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(12) United States Patent
Zhu et al.

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(54) **SYSTEM AND METHOD FOR AN OVENIZED SILICON PLATFORM USING SI/SIO$_2$ HYBRID SUPPORTS**

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(72) Inventors: **Weibin Zhu**, Saline, MI (US); **Navid Yazdi**, Ann Arbor, MI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days. days.

(21) Appl. No.: **15/470,670**

(22) Filed: **Mar. 27, 2017**

(65) **Prior Publication Data**

US 2017/0275157 A1 Sep. 28, 2017

Related U.S. Application Data

(60) Provisional application No. 62/390,385, filed on Mar. 28, 2016, provisional application No. 62/390,440, filed on Mar. 30, 2016.

(51) **Int. Cl.**

H01L 31/058	(2006.01)
H01L 21/76	(2006.01)
H01L 21/302	(2006.01)
H01L 21/461	(2006.01)
B81C 1/00	(2006.01)
H01L 27/12	(2006.01)
B81B 7/00	(2006.01)

(52) **U.S. Cl.**

CPC ***B81C 1/0069*** (2013.01); ***B81B 7/0019*** (2013.01); ***H01L 27/1207*** (2013.01); *B81B 2201/0228* (2013.01); *B81B 2201/0278* (2013.01); *B81B 2207/07* (2013.01); *B81B 2207/99* (2013.01); *B81C 2201/0126* (2013.01); *B81C 2201/0132* (2013.01)

(58) **Field of Classification Search**

CPC .. B81C 1/0069; B81B 7/0019; H01L 27/1207
USPC 257/467; 438/424, 427, 712
See application file for complete search history.

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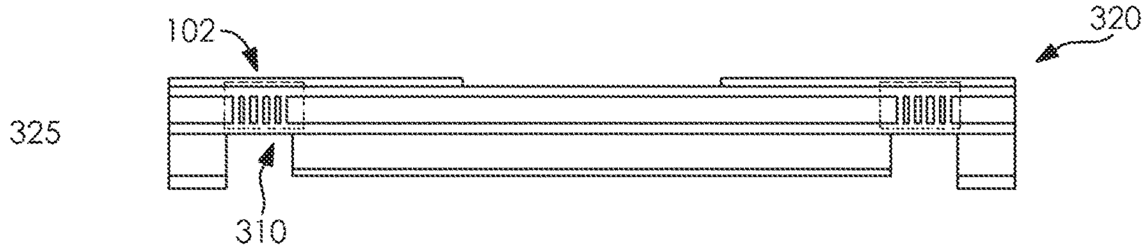
Primary Examiner — David S Blum

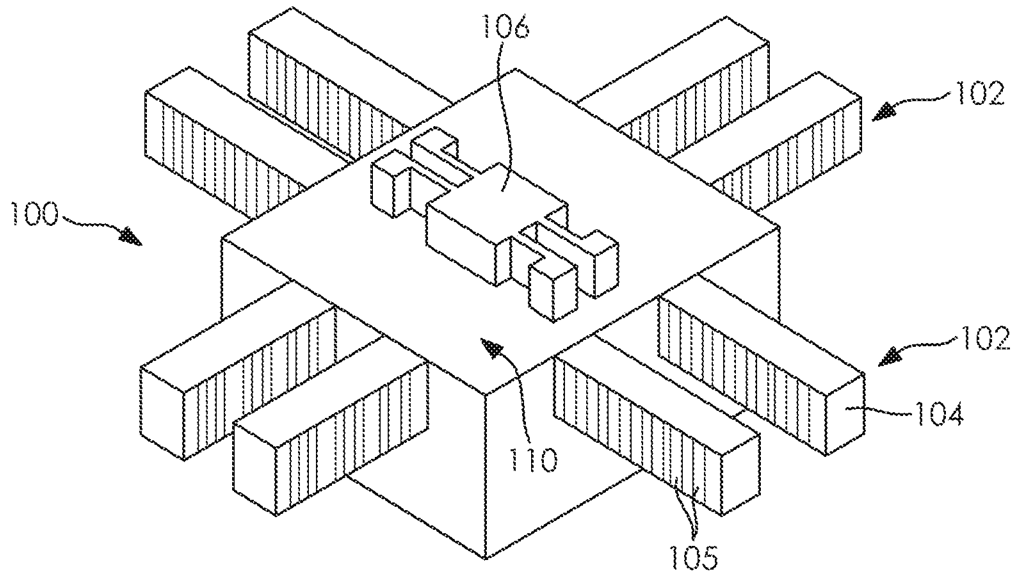
(74) *Attorney, Agent, or Firm* — James M. Smedley LLC; James Michael Smedley, Esq.

(57) **ABSTRACT**

The present invention generally relates to an ovenized platform and a fabrication process thereof. Specifically, the invention relates to an ovenized hybrid Si/SiO$_2$ platform compatible with typical CMOS and MEMS fabrication processes and methods of its manufacture. Embodiments of the invention may include support arms, CMOS circuitry, temperature sensors, IMUs, and/or heaters among other elements.

20 Claims, 23 Drawing Sheets





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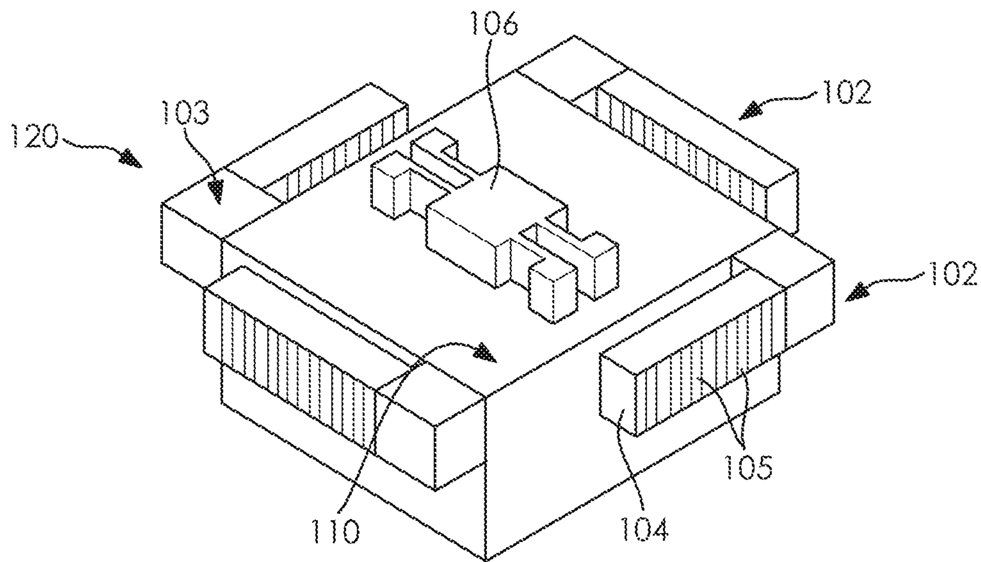


FIG. 1B

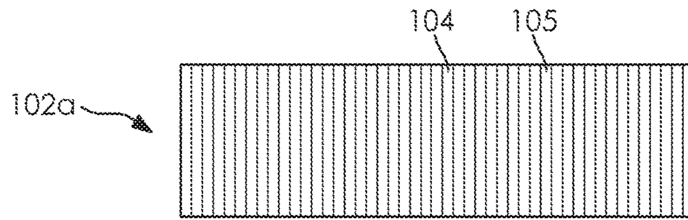
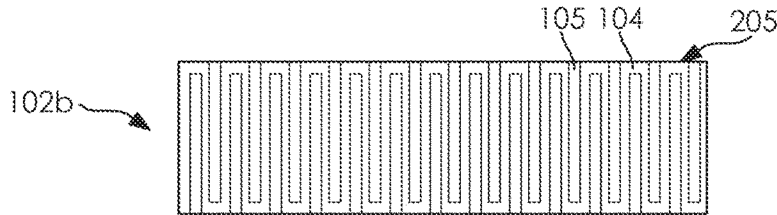


FIG. 2A



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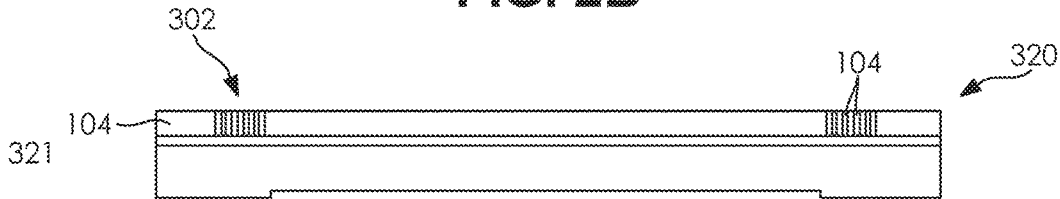


FIG. 3A

FIG. 3B

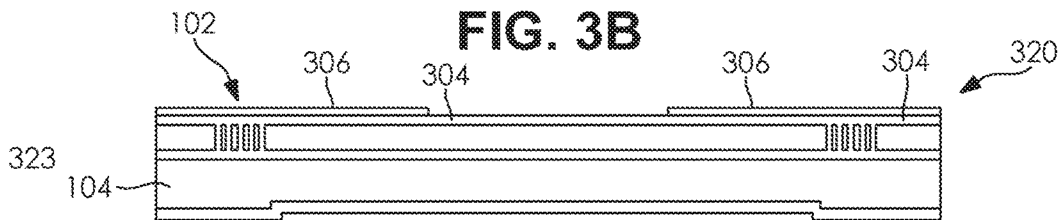


FIG. 3C

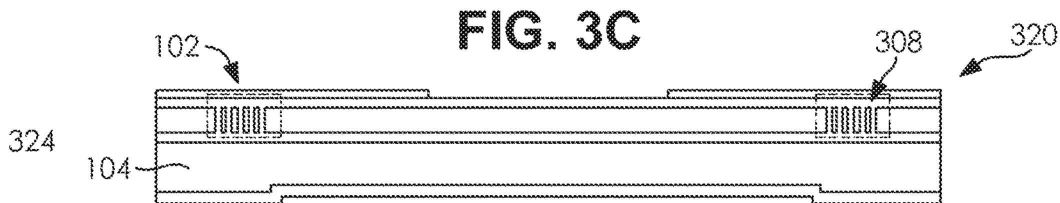


FIG. 3D

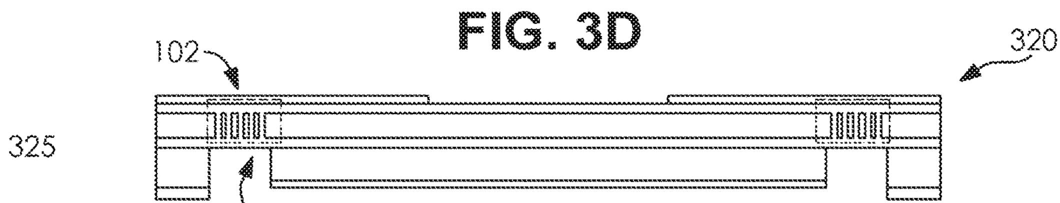


FIG. 3E

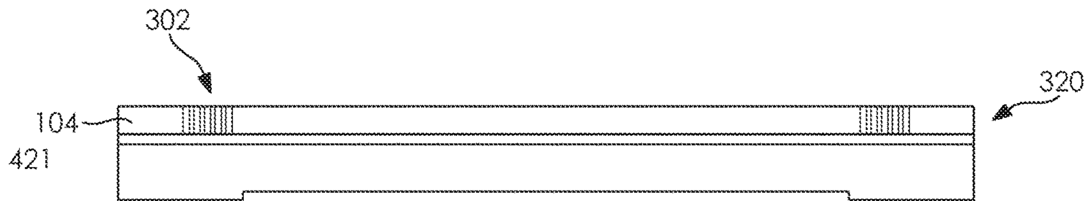


FIG. 4A

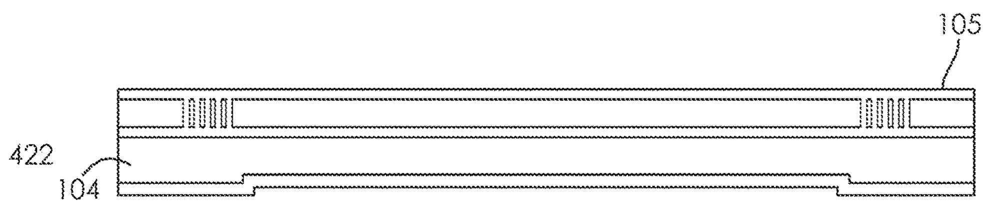
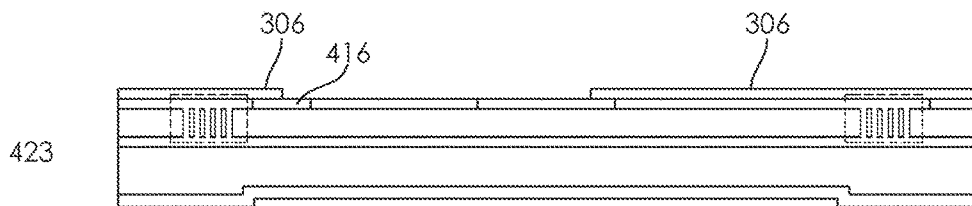


FIG. 4B



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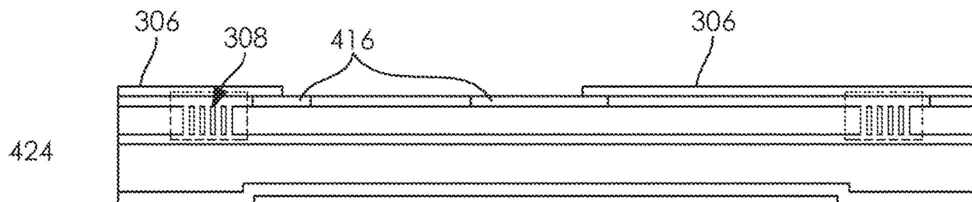


FIG. 4D

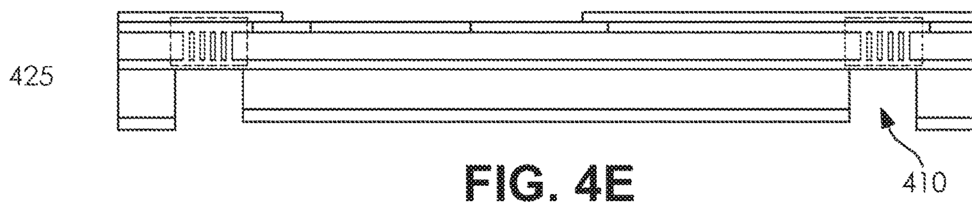
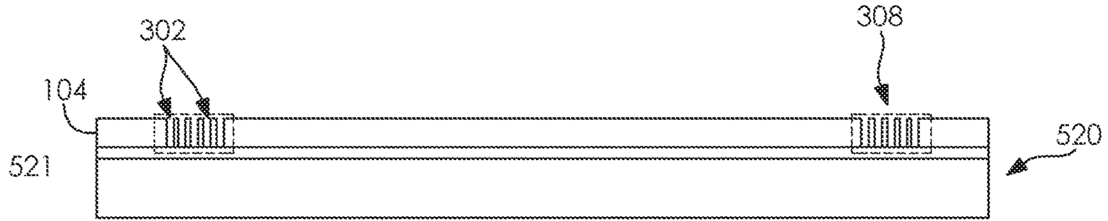


FIG. 4E



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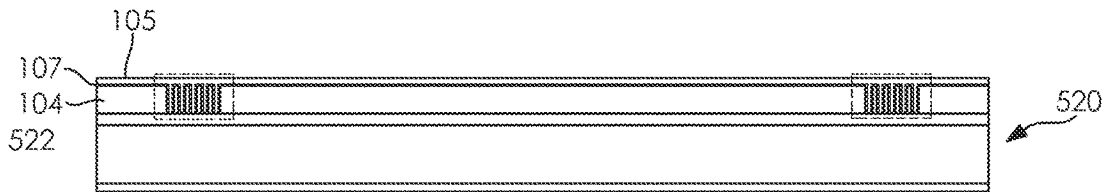
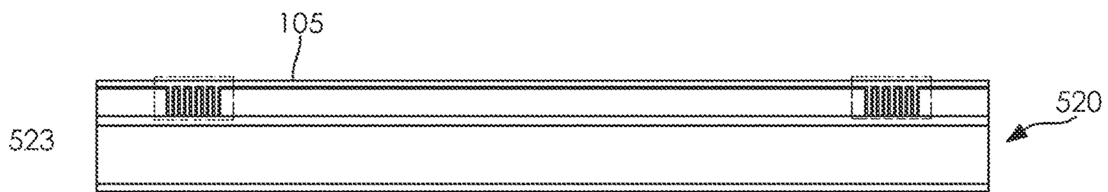


FIG. 5B



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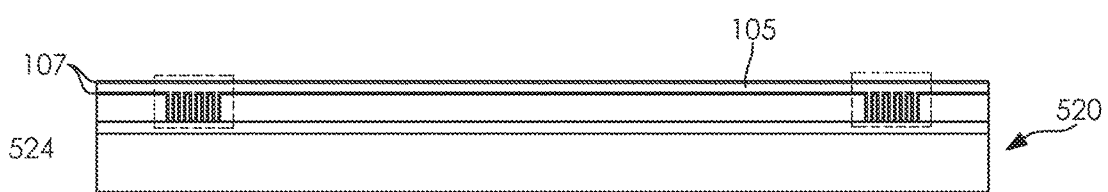

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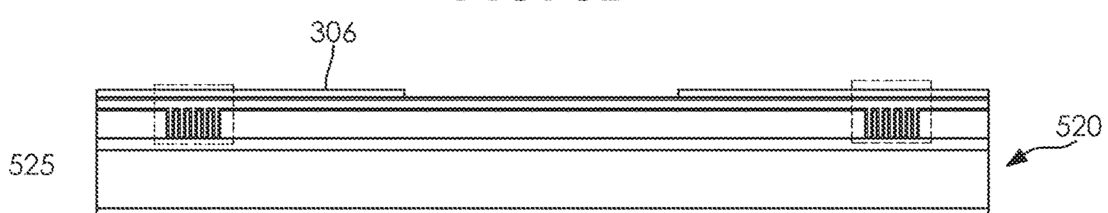


FIG. 5E

FIG. 5F

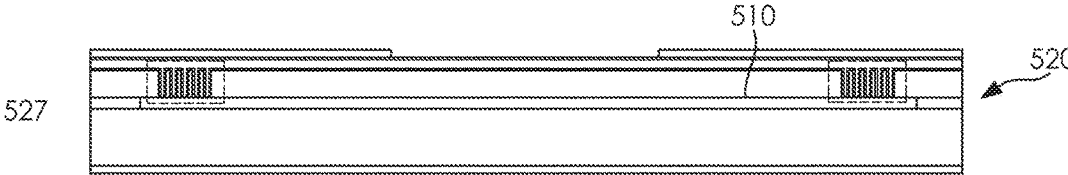


FIG. 5G

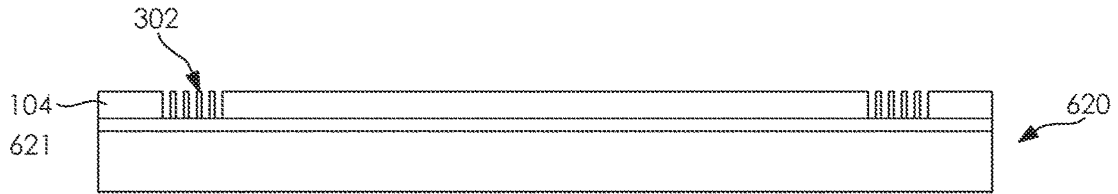
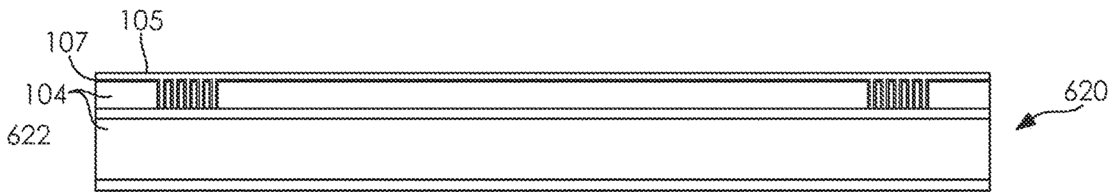


FIG. 6A



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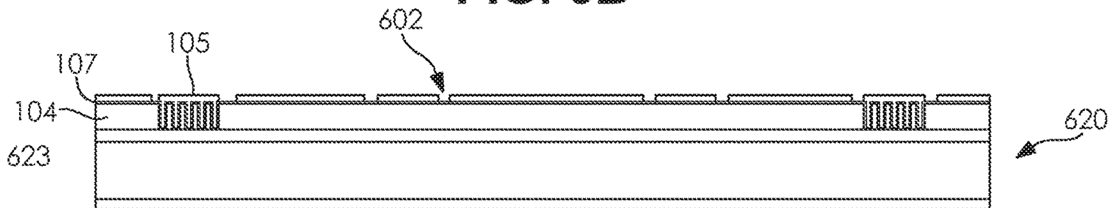

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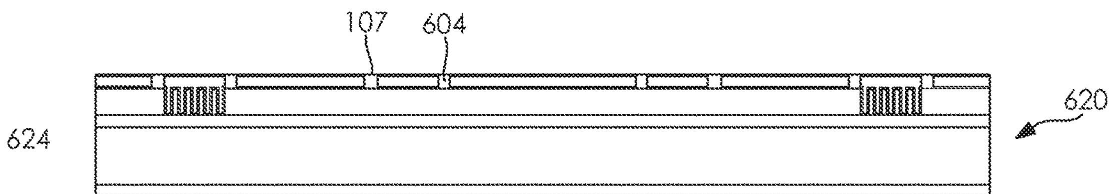

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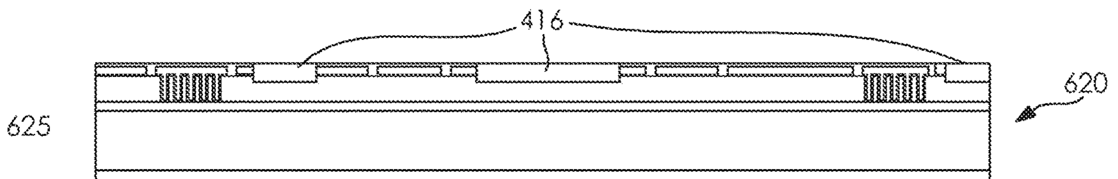

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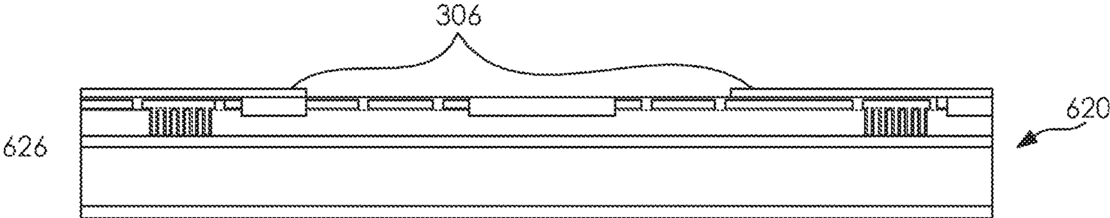

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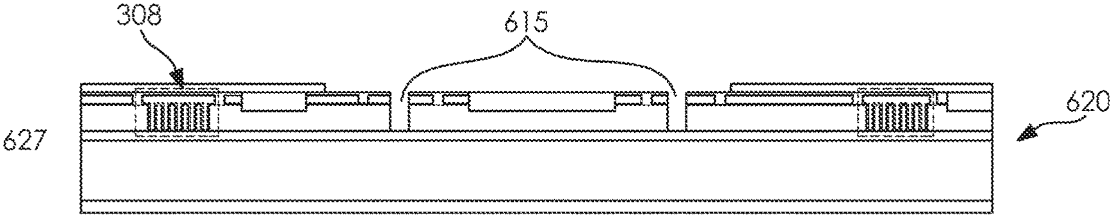

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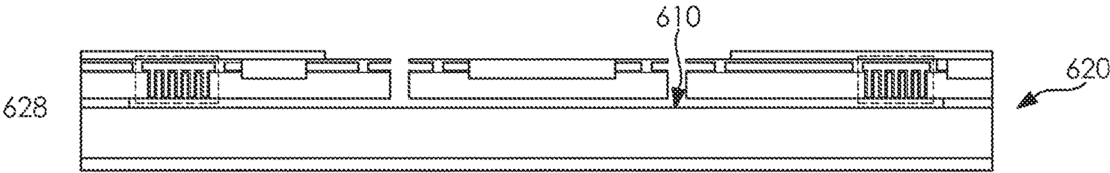


FIG. 6H

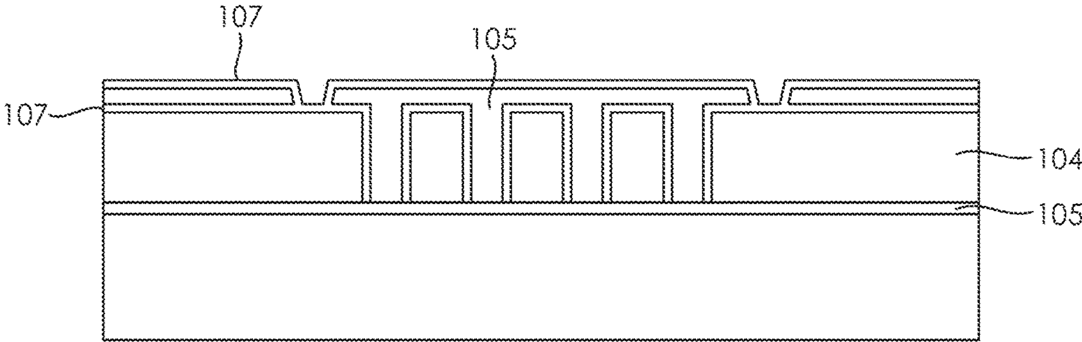


FIG. 7A

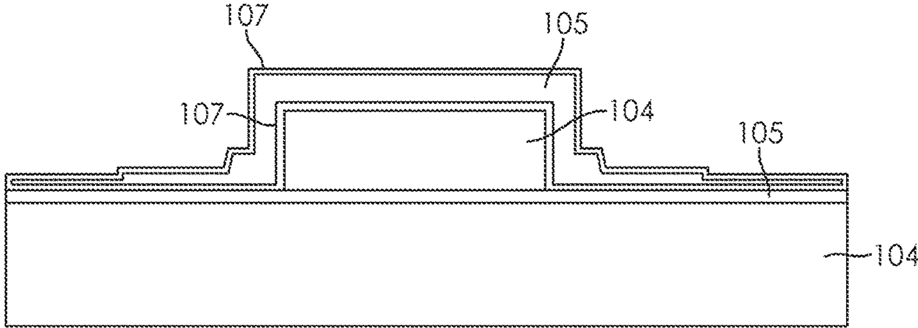


FIG. 7B

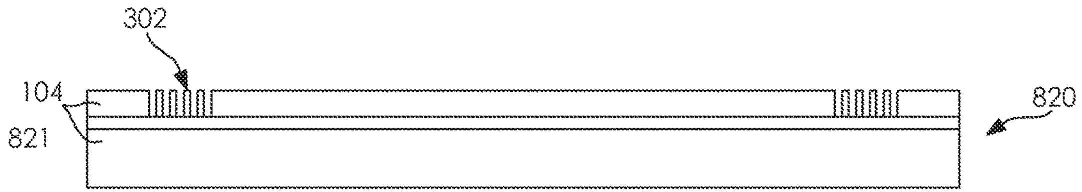
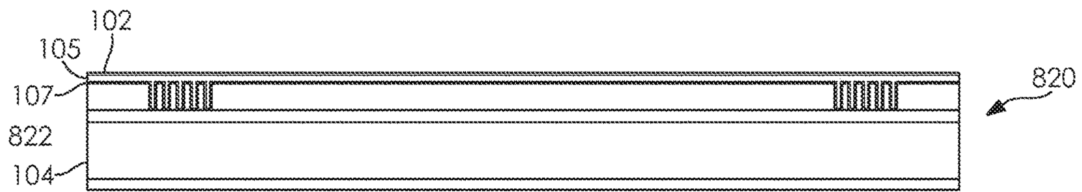


FIG. 8A



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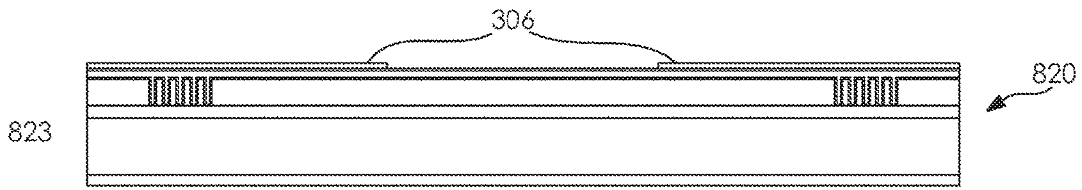

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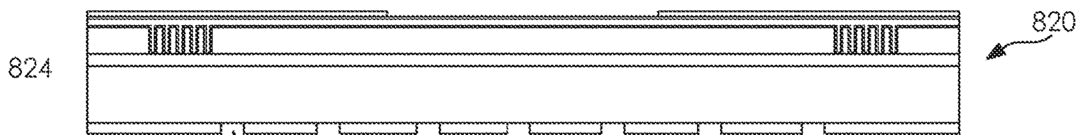

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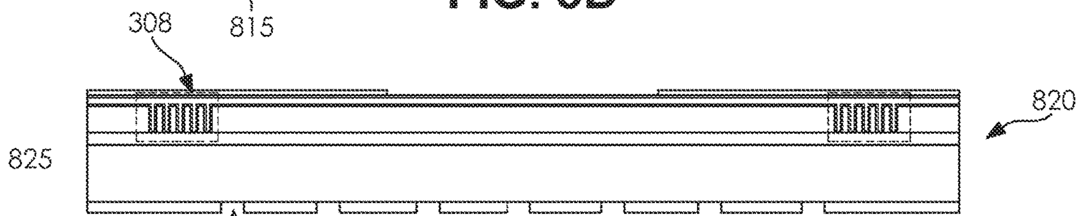

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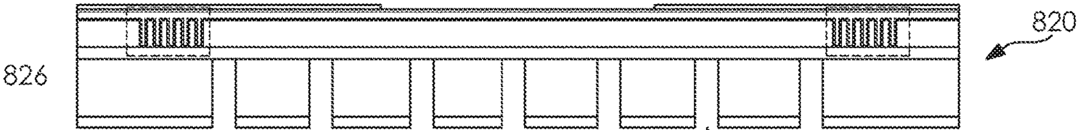

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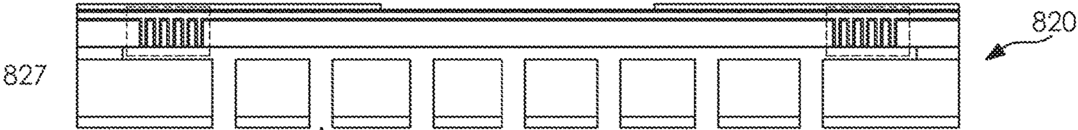

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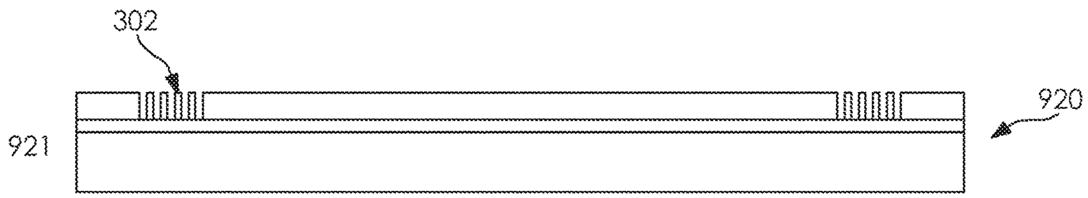


FIG. 9A

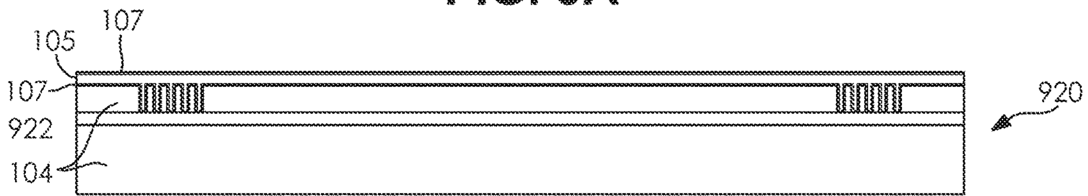


FIG. 9B

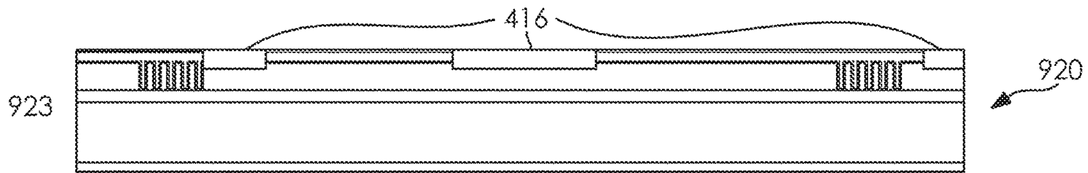
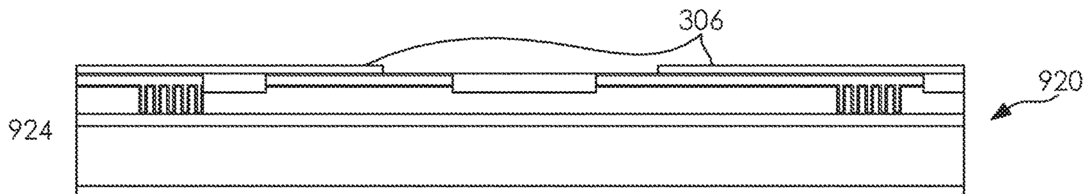


FIG. 9C



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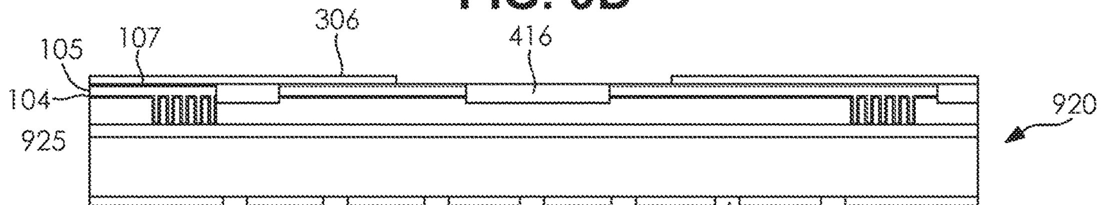

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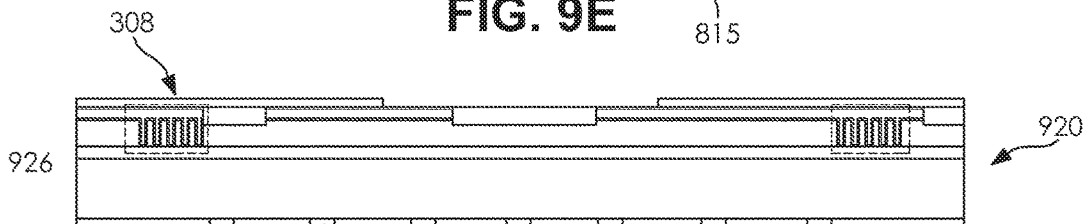

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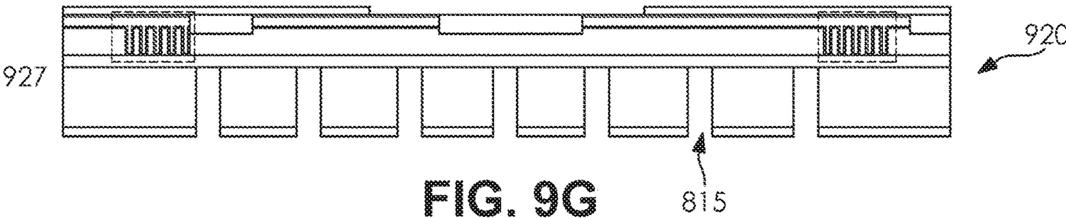

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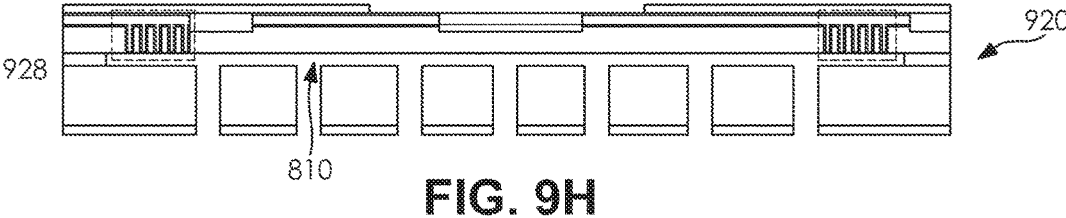


FIG. 9H

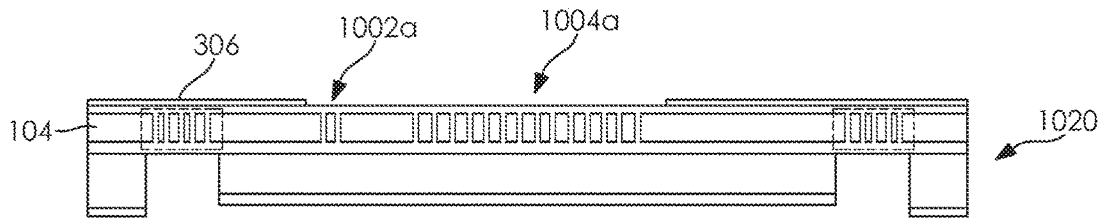
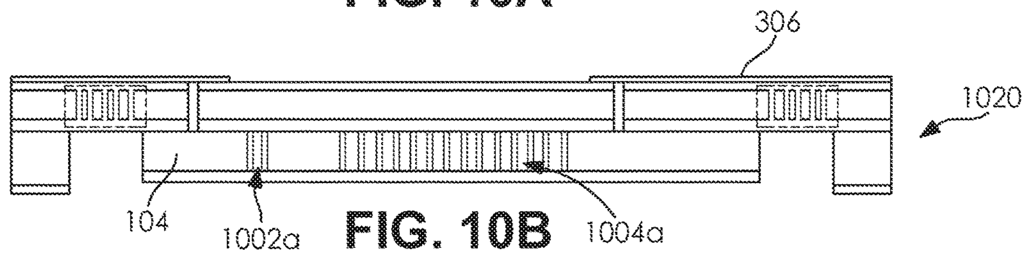


FIG. 10A



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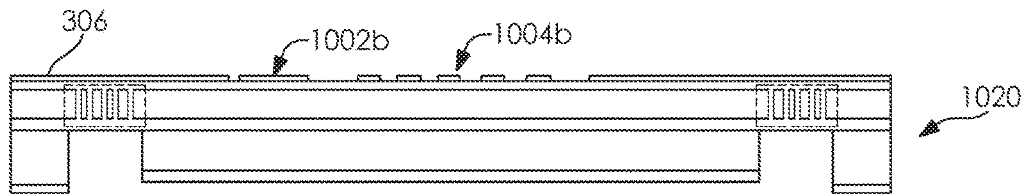

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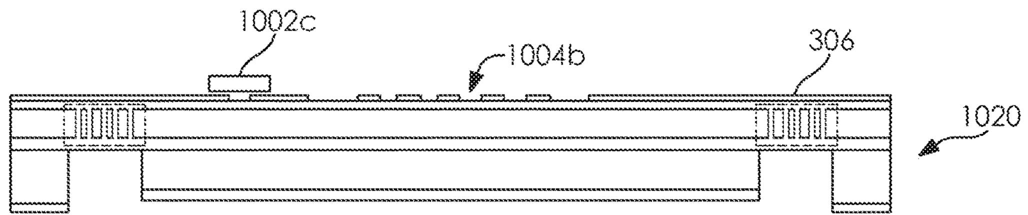

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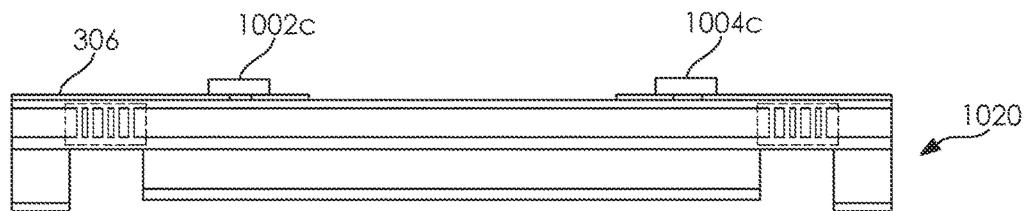

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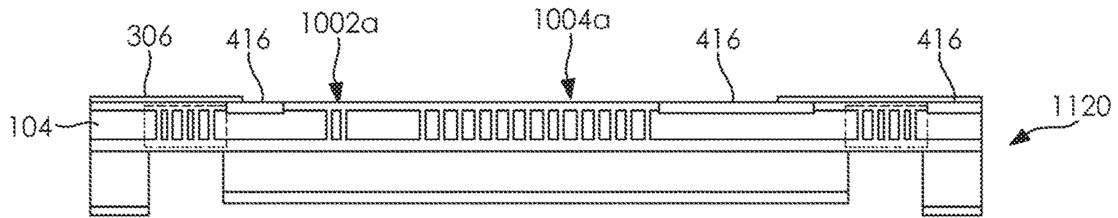
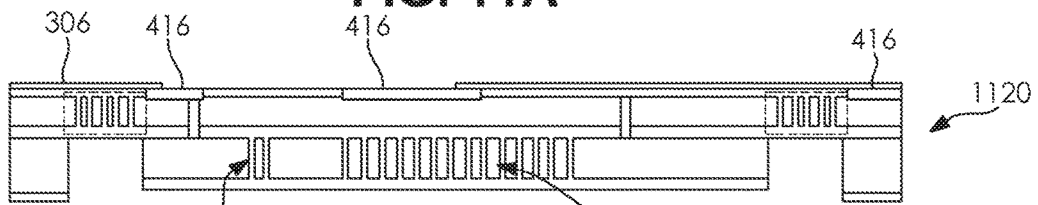


FIG. 11A



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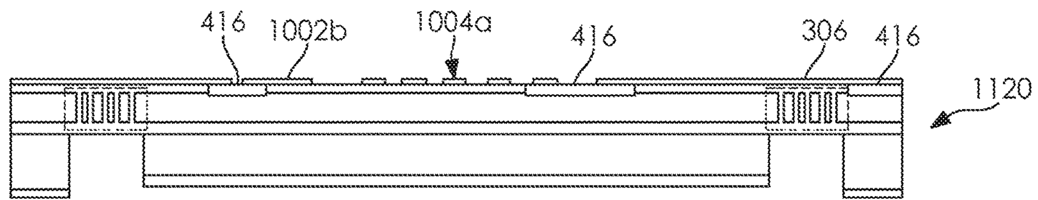

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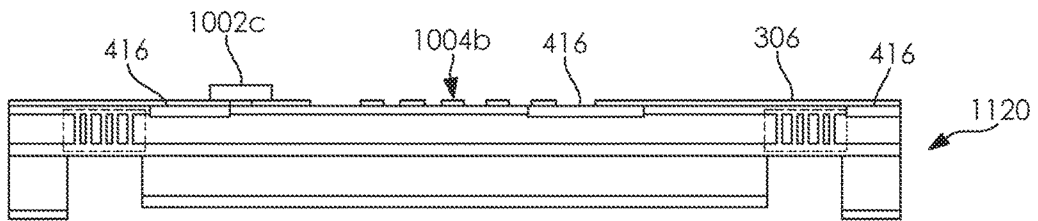
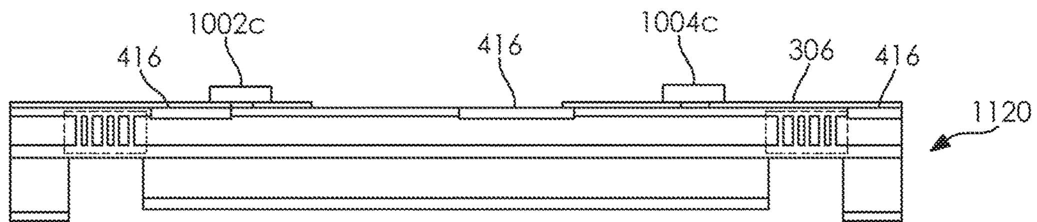


FIG. 11D



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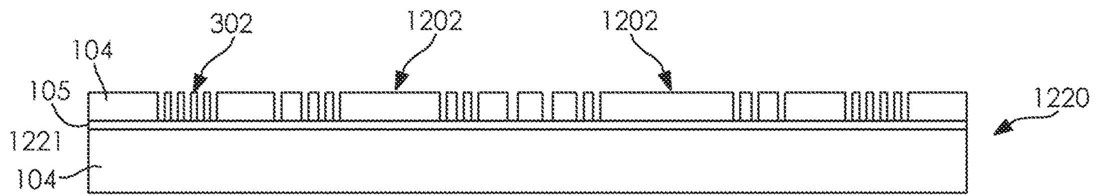


FIG. 12A

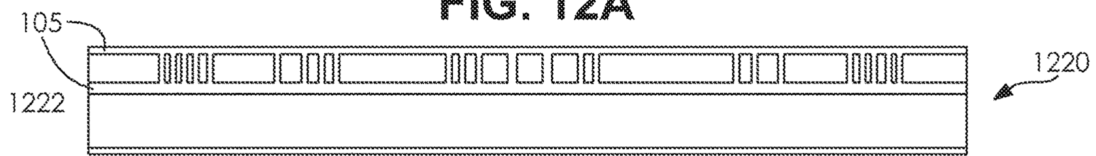


FIG. 12B

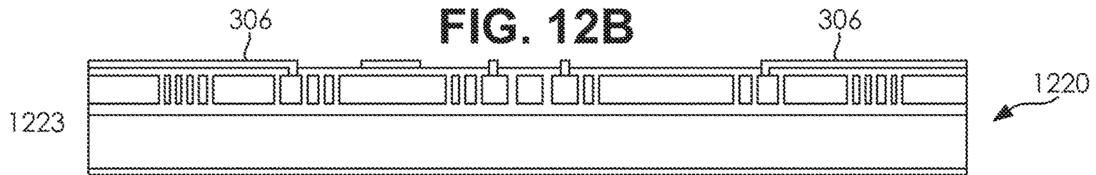
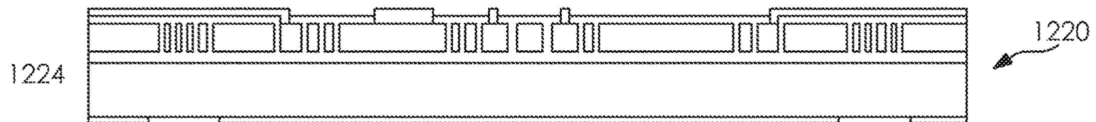


FIG. 12C



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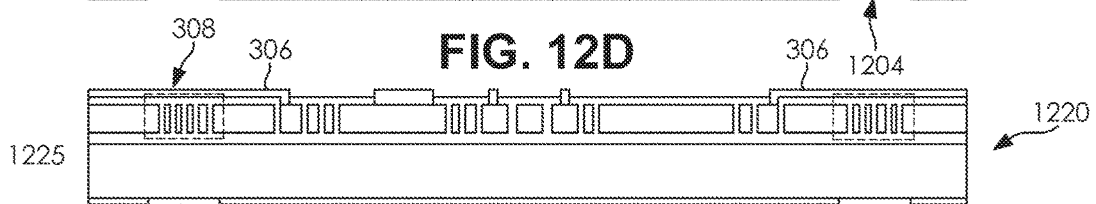

FIG. 12E

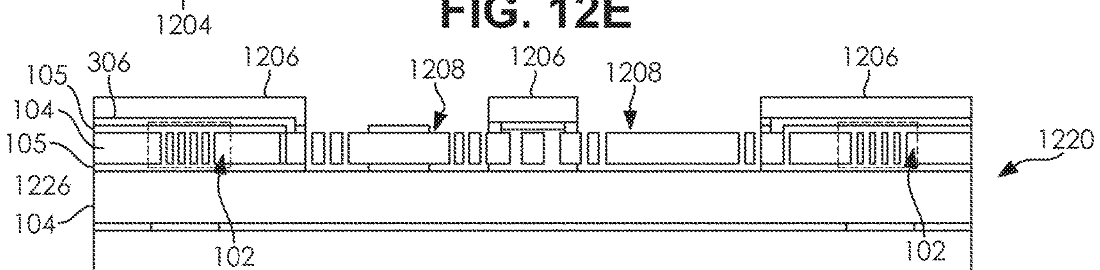

FIG. 12F

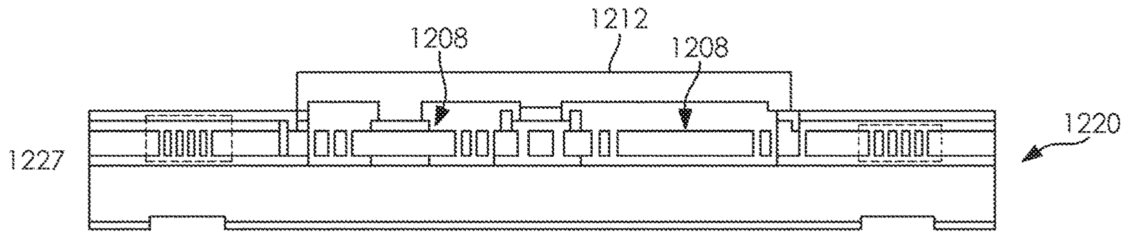

FIG. 12G

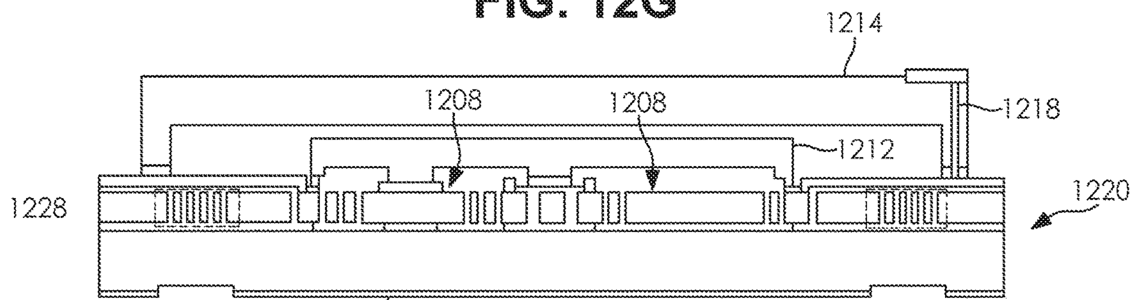

FIG. 12H

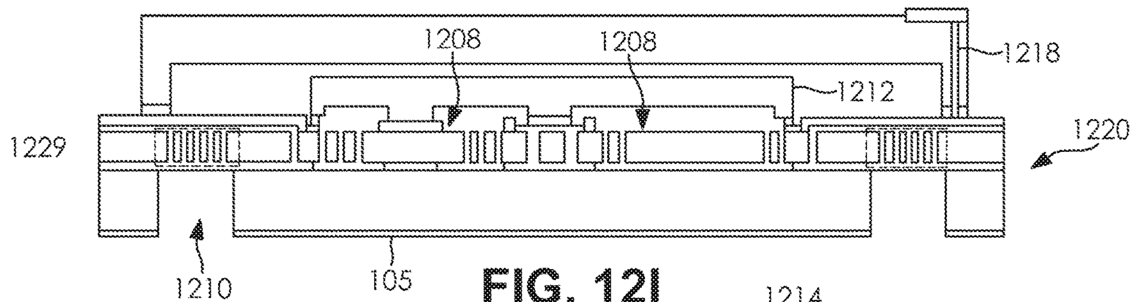

FIG. 12I

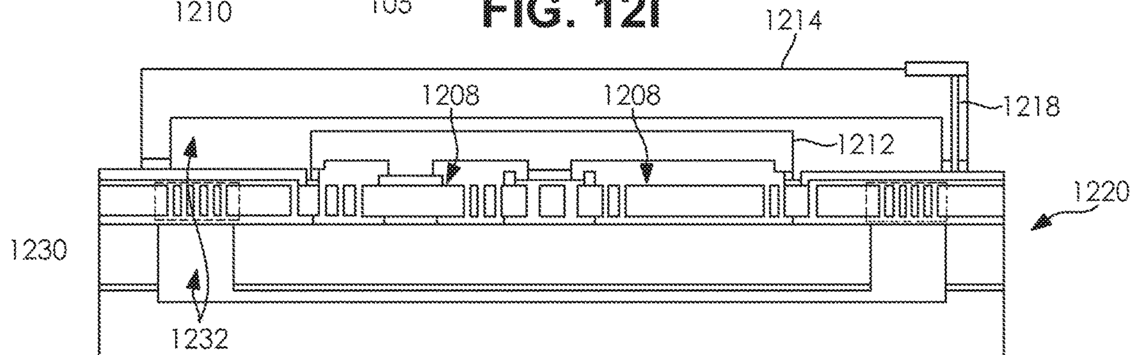

FIG. 12J

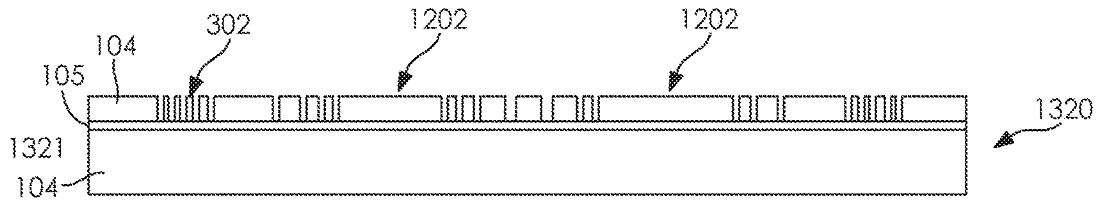

FIG. 13A

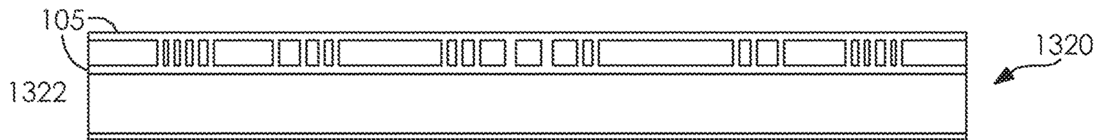

FIG. 13B

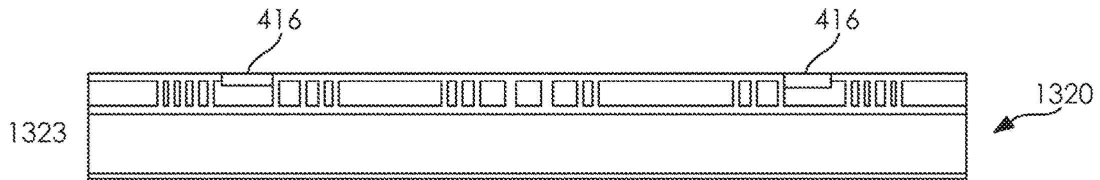

FIG. 13C

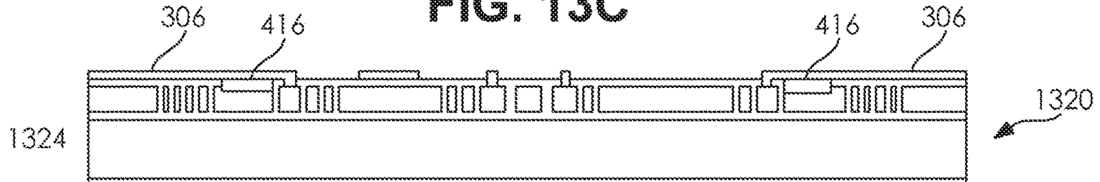

FIG. 13D

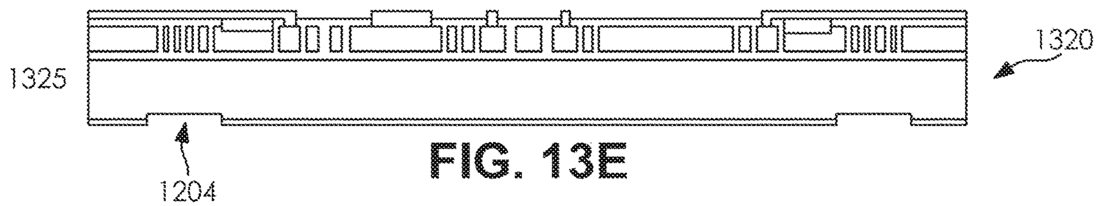

FIG. 13E

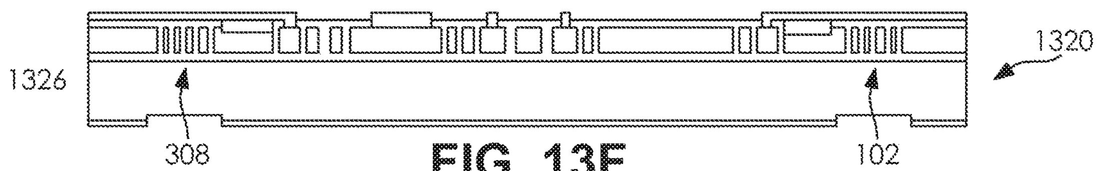

FIG. 13F

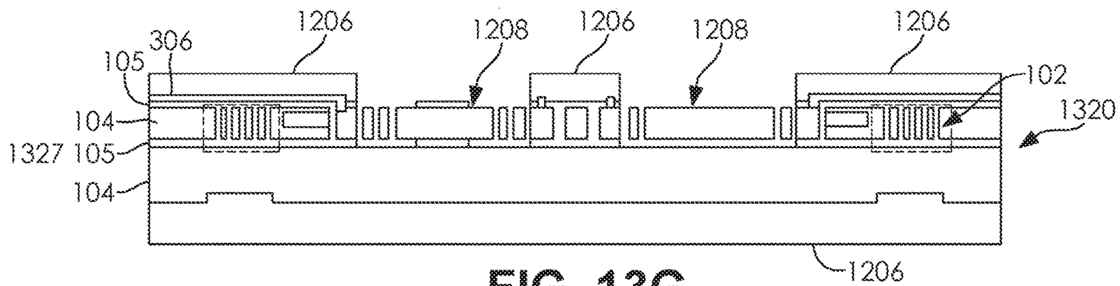

FIG. 13G

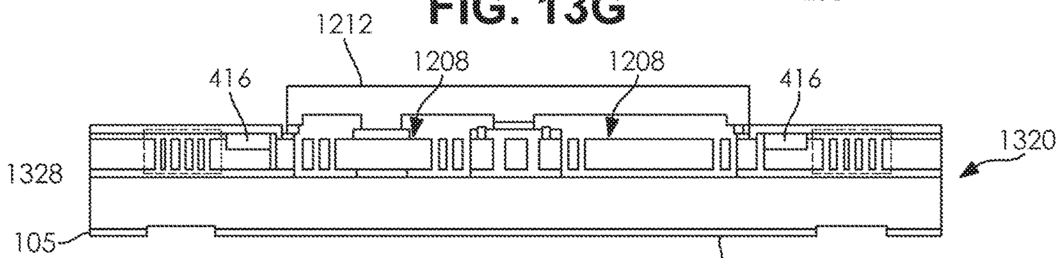

FIG. 13H

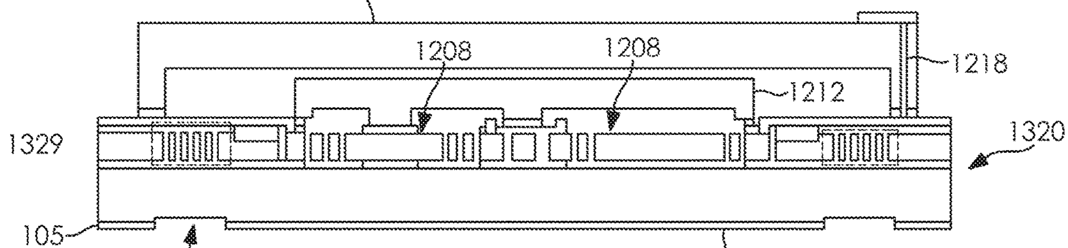

FIG. 13I

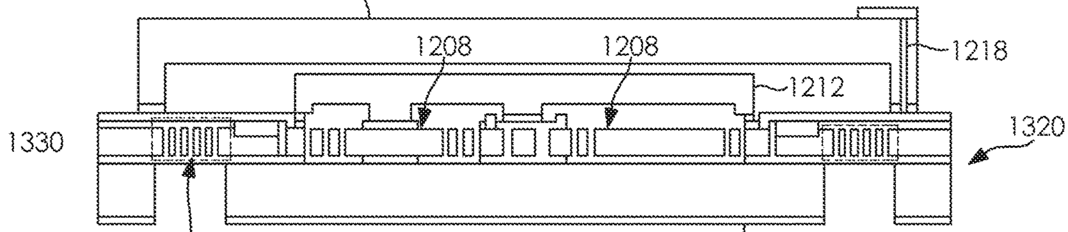

FIG. 13J

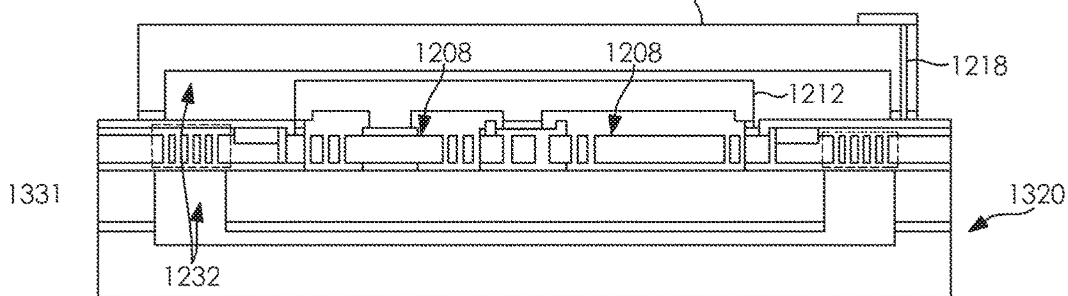

FIG. 13K

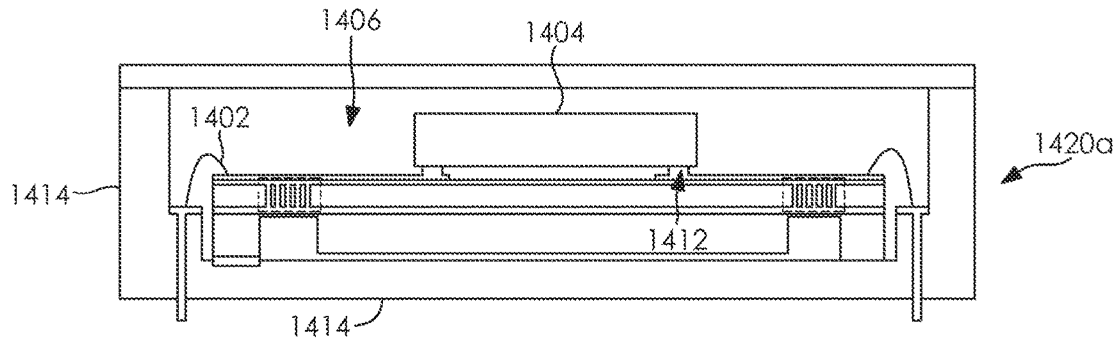

FIG. 14A

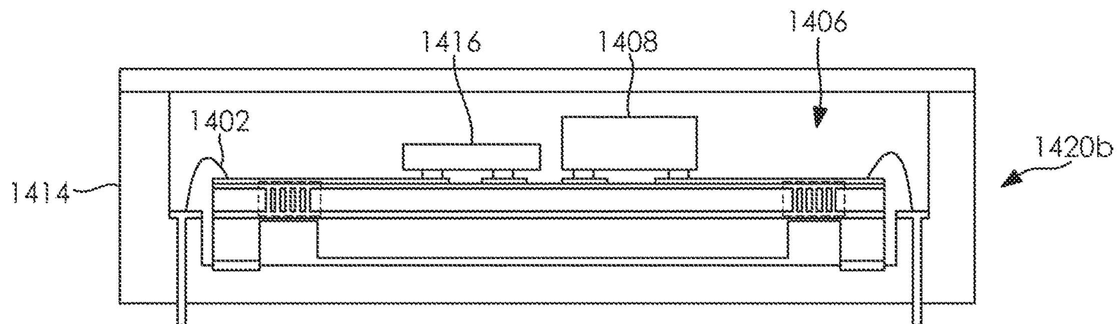

FIG. 14B

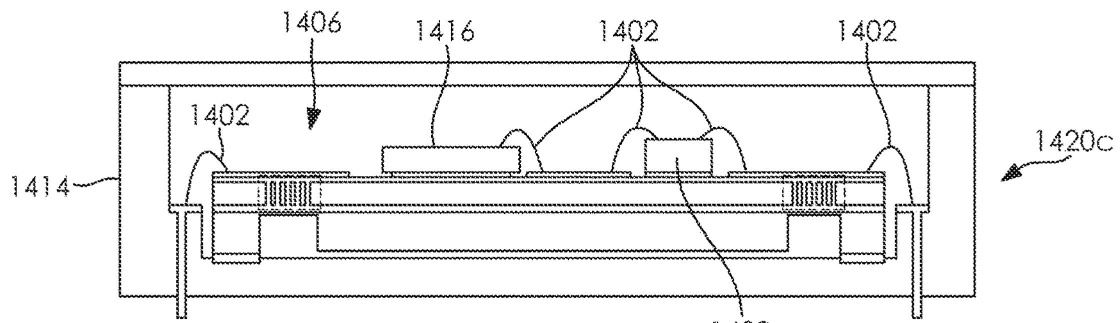

FIG. 14C

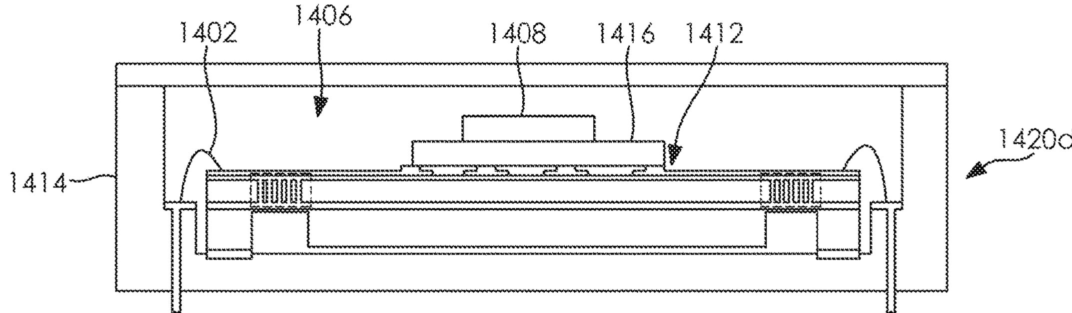

FIG. 14D

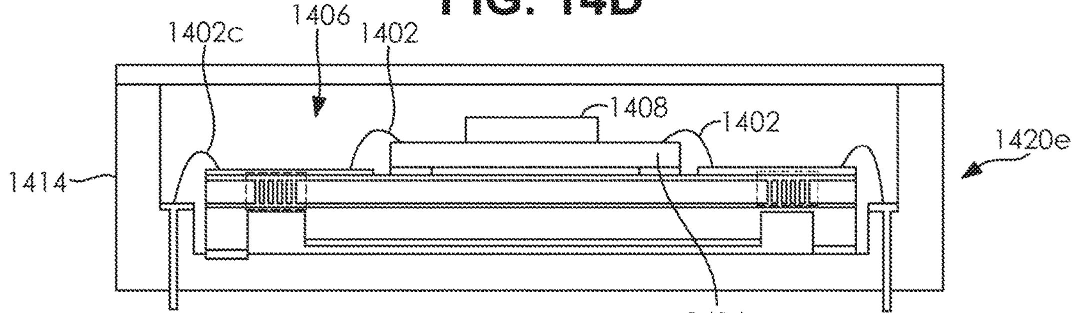

FIG. 14E

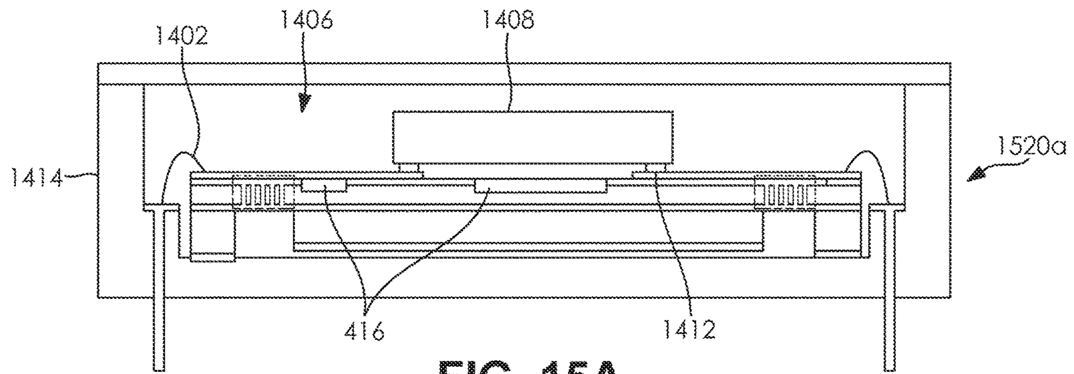

FIG. 15A

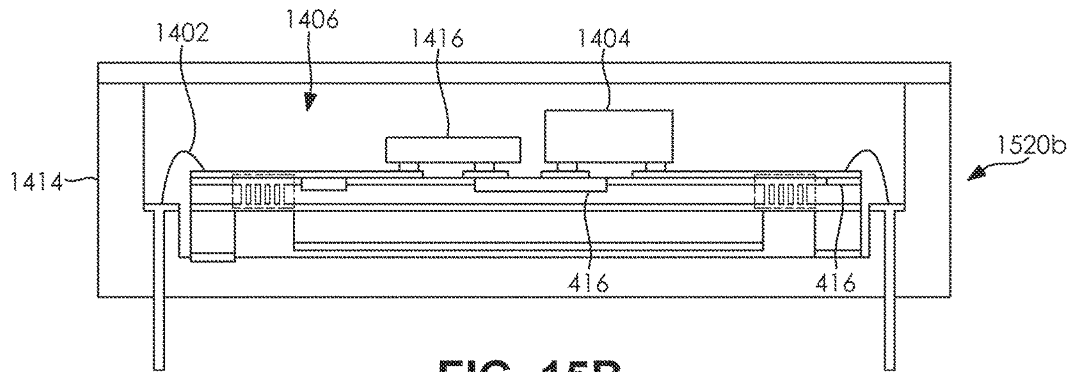

FIG. 15B

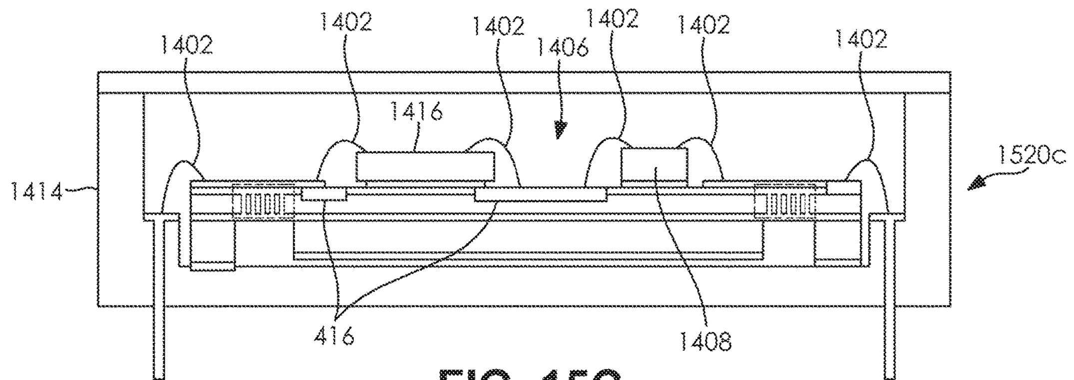

FIG. 15C

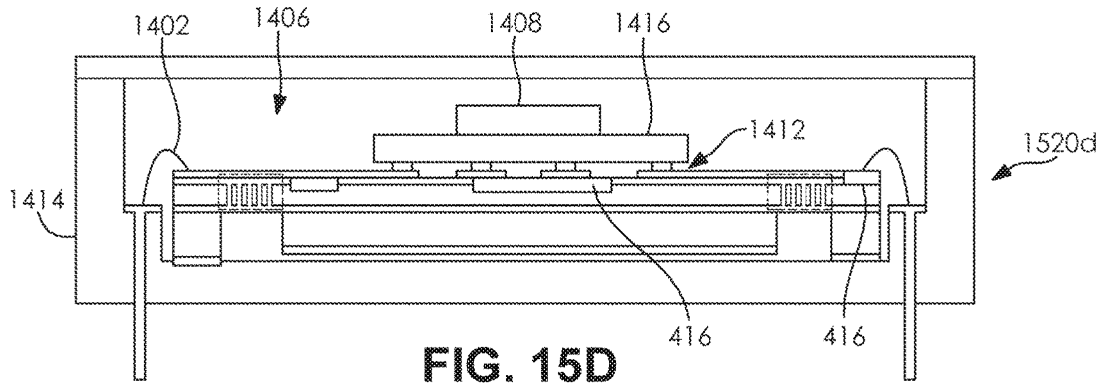

FIG. 15D

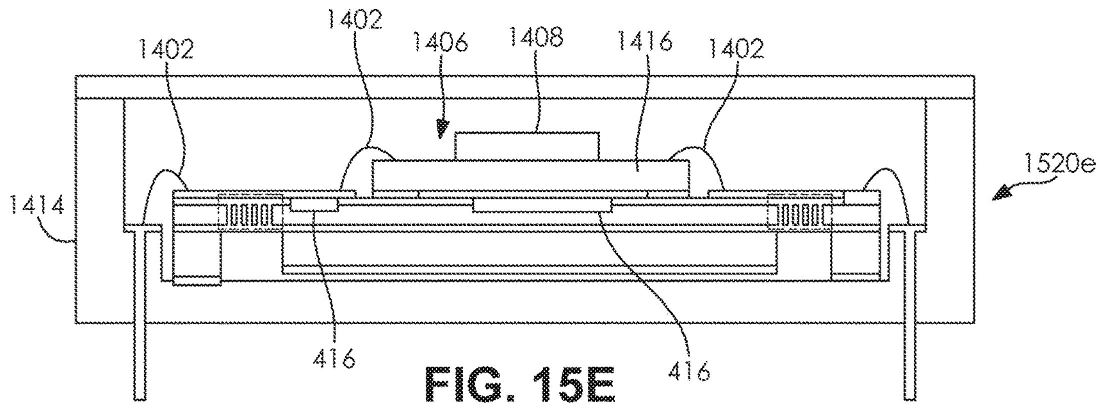

FIG. 15E

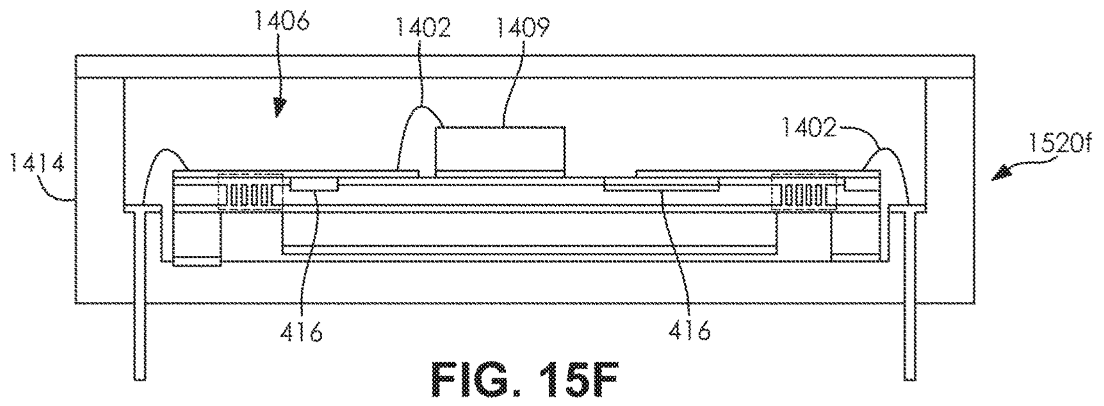

FIG. 15F

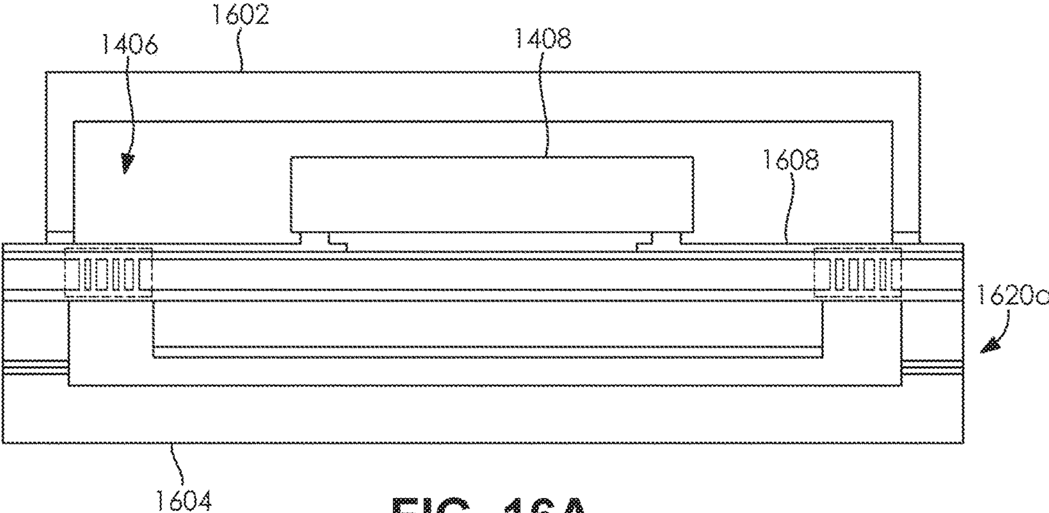

FIG. 16A

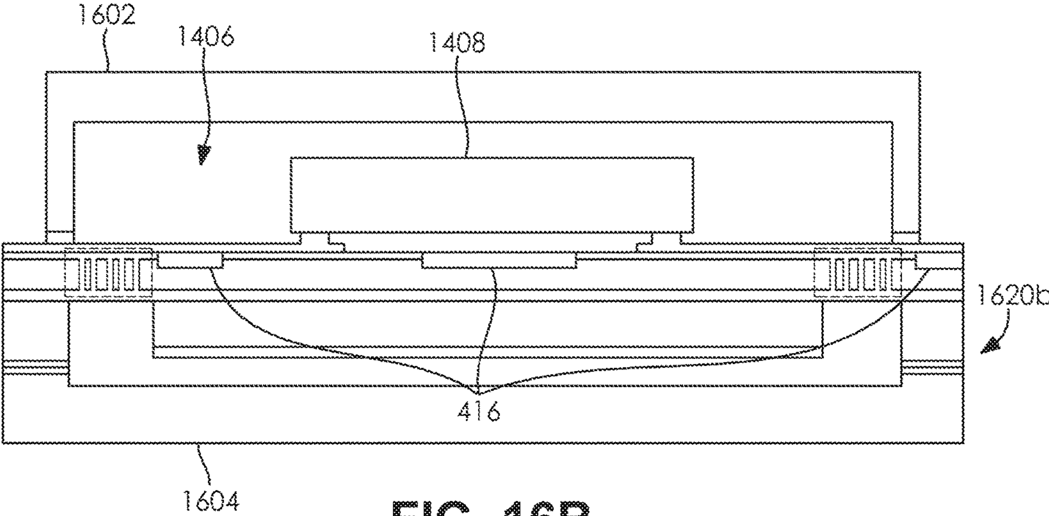

FIG. 16B

SYSTEM AND METHOD FOR AN OVENIZED SILICON PLATFORM USING SI/SIO_2 HYBRID SUPPORTS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Patent Application No. 62/390,440, filed on Mar. 30, 2016, and U.S. Provisional Patent Application No. 62/390,385, filed on Mar. 28, 2016, both of which are hereby incorporated by reference in their entirety.

GOVERNMENT SUPPORT

This invention was made with government support under contract number: W911NF-15-P-0049 awarded by US Army on behalf of Defense Advanced Research Projects Agency (DARPA). The government has certain rights in the invention.

FIELD OF THE INVENTION

The present invention generally relates to an ovenized silicon platform and a method for its manufacture and packaging. Specifically, the invention relates to a hybrid Si/SiO_2 platform structure with supports and method of fabrication thereof. Embodiments of the invention are configured to operate an electronic device, sensor, or resonator at a fixed temperature resulting in a high stability and accuracy of operation thereof across varying environmental temperature conditions.

BACKGROUND OF THE INVENTION

The technical performance requirements of microelectromechanical systems (MEMS) inertial measurement units (IMUs) have been challenging to meet for military, aerospace and high-end industrial and commercial market applications. Such high-end performance goals are, for example, that the bias and scale factor stability of the IMUs should be better than 1°/hr and 10 ppm for a gyroscope and better than 1 mg and 1 ppm for an accelerometer across a −40° C. to +85° C. temperature range.

Using an ovenized platform is intended to improve a given device's performance stability by holding the device at a relatively uniform stable temperature in a vacuumed enclosure. Such an approach isolates the devices from the environmental changes and facilitates the achievement of the abovementioned high performance goals. Over the past two decades, utilizing long suspended silicon support structures has become a common approach in MEMS fabrication in an attempt to provide the desired thermal isolation for a suspended silicon platform. However, this approach is often plagued with a number of drawbacks and limitations. For instance, due to the high thermal conductivity of silicon, in order to achieve the thermal isolation requirements necessary for the accurate performance of an IMU, the suspended silicon structures need to be very long and compliant and are, therefore, not very suitable for inertial sensing applications.

Additionally, until now, a glass substrate has been used to facilitate thermal isolation in the fabrication of the ovenized platform due to the very low thermal conductivity of SiO_2. However, the deficiency of this method is that the fabrication process of a glass platform is typically not compatible with standard complementary metal-oxide-semiconductor (CMOS) and MEMS manufacturing processes. Sensor and platform integration can often be achieved on a die-level assembly making glass an impractical substrate. Furthermore, although there is a requirement for the temperature gradient inside the platform is to be minimized, such a requirement is difficult to meet with a low-conductivity material such as glass. Further, the thermal mismatch between glass platform and mounted sensor can potentially cause large stress when the platform form temperature increases.

Accordingly, there is a need in the art for an ovenized silicon platform with high technical performance specifications. More specifically, there is a need for a micro-oven platform incorporating a MEMS IMU providing high-temperature isolation as well as low-displacement and high-shock survival in the face of environment vibrations and mechanical impacts with unprecedented bias and scale factor stability that is fully compatible with accepted CMOS and MEMS fabrication processes. These and other features and advantages of the present invention will be explained and will become obvious to one skilled in the art through the summary of the invention that follows.

SUMMARY OF THE INVENTION

In the present invention, a generic micro-ovenization and high precision temperature-controlled Si platform is provided. This platform achieves an unprecedented bias and scale factor stability for MEMS inertial sensors by employing an innovative micro-oven platform and precise oven-temperature controls as described herein. The present silicon micro-oven platform is fully-compatible with commonly used CMOS and MEMS fabrication processes. It also provides high temperature isolation in addition to low displacement as well as high-shock tolerance and survival in the event of environment vibrations and mechanical impacts. The present invention incorporates a high-precision micro-oven temperature control to achieve temperature control precision of 0.01° C. or less using various techniques to integrate temperature sensors and heaters, including using thin film low-cost deposited resistors in standard MEMS and integrated circuit (IC) fabrication processes, using IC fabrication processes with built-in temperature sensors or commercial surface mount temperature resistors. In this manner, the present invention provides versatile high-yield fabrication and packaging processes that are suitable for both wafer-level sensor fabrication and die level sensor assembly.

According to an embodiment of the present invention, an ovenized silicon platform comprises: at least one silicon layer, at least one silicon oxide layer, a hybrid Si/SiO2 platform support structure, wherein said support structure is formed by depositing silicon oxide within trenches formed by a deep reactive ion etching of a silicon layer to create alternating layers of silicon and silicon oxide configured to thermally isolate the platform from temperature fluctuations, and at least one thin-film electrical interconnect displaced on the top surface of said platform.

According to an embodiment of the present invention, the platform comprises at least one element selected from the group comprising CMOS circuitry, thermal sensor, heater, and inertial sensor. In an embodiment of the present invention the alternating layers of silicon and silicon oxide within the platform support structure are separated by a layer of silicon nitride. Additionally, in an embodiment of the present invention at least one silicon layer is a device layer of a silicon-on-isolator wafer.

According to an embodiment of the present invention, the platform comprises at least one thermal sensor and at least one heater wherein said at least one thermal sensor and said at least one heater are each positioned within a layer of silicon. The platform may also comprise at least one thermal sensor and at least one heater wherein said at least one thermal sensor and said at least one heater are each positioned on the top surface of said platform in accordance with an embodiment of the present invention. Additionally, in an embodiment of the present invention the thin-film electrical interconnect is a trace comprising metal or polysilicon.

According to an embodiment of the present invention, a method for fabricating an ovenized silicon platform comprises the steps of: deep-reactive-ion-etching trenches into a layer of silicon on one side of said platform, forming a recess on a side of the platform opposite to that of said trenches, depositing a layer of oxide onto a top layer of the platform to refill said trenches; attaching conductive traces onto a surface of the platform, and patterning a platform support structure that provides thermal isolation for the platform, releasing said support structure.

According to an embodiment of the present invention, the method also comprises the step of integrating CMOS circuitry with the platform. In another embodiment, the method may also include the steps of depositing a first layer of nitride onto a layer of silicon prior to depositing a layer of oxide on a top layer of the platform, and then depositing a second layer of nitride onto the layer of oxide to create a layer of oxide sandwiched between layers of nitride deposited on a top surface of the platform. The method for fabricating an ovenized silicon platform may further comprise the steps of patterning the silicon oxide layer to create depressions therein, and encapsulating said depressions with nitride during the deposition of the second layer of nitride to create lateral etch stops.

According to an embodiment of the present invention, the method for fabricating an ovenized silicon platform comprises the steps of: defining at least one inertial sensor along with said trenches during the deep-reactive-ion-etching step, releasing said at least one inertial sensor, fitting a sensor cap over said at least one inertial sensor, fitting a top cap on a top surface of said platform, and fitting a bottom cap on a bottom surface of said platform. In an embodiment of the present invention the method may further comprise the step of integrating CMOS circuitry with the platform.

According to an embodiment of the present invention, the method for fabricating an ovenized silicon platform may comprise the steps of: attaching at least one of an unpackaged sensor or a packaged sensor to a top surface of the platform, attaching said platform within an electronic chip package, and covering said package with a lid. In an embodiment of the present invention the method may further comprise the steps of: vacuum sealing said ceramic package, and attaching a sensor by either flip-chip bonding, eutectic bonding, or wirebond connection.

The foregoing summary of the present invention with the preferred embodiments should not be construed to limit the scope of the invention. It should be understood and obvious to one skilled in the art that the embodiments of the invention thus described may be further modified without departing from the spirit and scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a perspective view of an platform with Si/SiO_2 hybrid structure comprising a straight beam support arm design in accordance with an embodiment of the present invention;

FIG. **1**B is a perspective view of an platform with Si/SiO_2 hybrid structure comprising a crab-leg support arm design in accordance with an embodiment of the present invention;

FIGS. **2**A-**2**B are top view illustrations of two alternative designs of the alternating Si/SiO_2 pattern of the support arms in accordance with embodiments of the present invention;

FIGS. **3**A-**3**E show a cross-sectional view of the steps of a platform fabrication process flow in accordance with an embodiment of the present invention;

FIGS. **4**A-**4**E show a cross-sectional view of the steps of a platform fabrication process flow incorporating a standard CMOS integration process in accordance with an embodiment of the present invention;

FIGS. **5**A-**5**G show a cross-sectional view of the steps of a platform fabrication process flow in accordance with another embodiment of the present invention;

FIGS. **6**A-**6**H show a cross-sectional view of the steps of a platform fabrication process flow incorporating a standard CMOS integration process in accordance with another embodiment of the present invention;

FIG. **7**A illustrates cross-sectional view of a steps of a Si/SiO_2 hybrid support arm along the heat conduction path in accordance with an embodiment of the present invention;

FIG. **7**B illustrates cross-sectional view of a steps of a Si/SiO_2 hybrid support arm perpendicular to the heat conduction path in accordance with an embodiment of the present invention;

FIGS. **8**A-**8**G show a cross-sectional view of the steps of a platform fabrication process flow in accordance with an embodiment of the present invention;

FIGS. **9**A-**9**H show a cross-sectional view of the steps of a platform fabrication process flow incorporating a standard CMOS integration process in accordance with another embodiment of the present invention;

FIGS. **10**A-**10**E illustrate alternative temperature sensor and heater configurations on a platform respectively in accordance with alternative embodiments of the present invention;

FIGS. **11**A-**11**E illustrate alternative temperature sensor and heater configurations on a platform integrated with CMOS circuitry respectively in accordance with alternative embodiments of the present invention;

FIGS. **12**A-**12**J show a cross-sectional view of the steps of a platform fabrication process flow integrating inertial sensors with an ovenized platform in accordance with another embodiment of the present invention;

FIGS. **13**A-**13**K show a cross-sectional view of the steps of a platform fabrication process flow integrating inertial sensors along with CMOS circuitry with an ovenized platform in accordance with another embodiment of the present invention;

FIGS. **14**A-**14**E show cross-sectional views of alternative ovenized platform packaging schemes respectively in accordance with alternative embodiments of the present invention;

FIGS. **15**A-**15**F show a cross-sectional view of alternative ovenized platform packaging schemes incorporating CMOS circuitry respectively in accordance with alternative embodiments of the present invention;

FIG. **16**A illustrates a cross-sectional view of a wafer-level ovenized platform packaging scheme incorporating CMOS circuitry in accordance with an embodiment of the present invention; and

FIG. **16**B illustrates a cross-sectional view of a wafer-level ovenized platform packaging scheme in accordance with another embodiment of the present invention.

DETAILED SPECIFICATION

In the Summary above, in the Detailed Specification, the Claims below, and in the accompanying drawings, reference is made to particular features including method steps of the invention. It is to be understood that the disclosure of the invention in this specification includes all possible combinations of such particular features. For example, where a particular feature is disclosed in the context of a claim, that feature can also be used to the extent possible, in combination with and/or in the context of other particular aspects and embodiments of the invention and in the invention generally.

The term "comprises" and grammatical equivalents thereof are used herein to mean that other components, ingredients, steps, etc. are optionally present. For example, an article "comprising" (or "which comprises") components A, B, and C can consist of (i.e. contain only) components A, B, and C or can contain not only components A, B, and C but also one or more other components.

Where reference is made herein to a method comprising two or more defined steps, the defined steps can be carried out in any order or simultaneously (except where the context excludes that possibility), and the method can include one or more other steps which are carried out before any of the defined steps, between two of the defined steps, or after all the defined steps (except where the context exclude that possibility).

Embodiments of the present invention generally relate to an ovenized platform and a fabrication process thereof. Specifically, the invention relates to an ovenized hybrid Si/SiO_2 platform compatible with typical CMOS and MEMS fabrication processes and methods of its manufacture. Certain embodiments of the invention may include support arms, CMOS circuitry, temperature sensors, IMUs, and/or heaters among other elements.

The disclosed platform as well as its fabrication and packaging methods enable precise temperature control and thermal isolation from the environment for the sensors, IMUs, or other devices incorporated thereon. Generally, the operation of the oven at fixed temperatures is achieved by at least a precise temperature sensor and at least a heater on a Si platform supported by hybrid Si/SiO_2 support arms. The silicon layer has a high thermal-conductance that allows for a highly-uniform temperature across the platform. A control loop that is connected to the temperature sensor as well as the heater is utilized to obtain a high-accuracy stable fixed oven temperature. In order to minimize the heat loss due to convection, in a preferred embodiment of the present invention the platform is preferably packaged in a vacuum environment.

A preferred embodiment **100** of the invention, shown in FIG. **1**, employs a silicon platform **110** with a Si/SiO_2 hybrid structure. In this embodiment, the platform **110** has a sufficient thickness to ensure stability, a high level of thermal isolation for low-power operation, and rigid support beams **102** for resilience against shock or vibration. It should be understood by a person skilled in the art that the particular internal and exterior design and number of the Si/SiO_2 support arms **102** can vary based on the design requirements and that the various embodiments the invention discussed herein can incorporate any variation or configuration thereof. For example, the geometric design of each support arms can be that of a straight beam structure **101** as shown in FIG. **1**A, a crab-leg structure **103** as shown in FIG. **1**B, or any of a variety other geometric designs that are determined to be optimal based on design specifications and fabrication considerations in each instance. Other geometric designs that utilize the Si/SiO_2 hybrid structure are also feasible to provide good thermal isolation of the platform **110** structure.

Two design examples of the proposed Si/SiO_2 hybrid support arms **102** are illustrated in FIG. **2**. The formation of either alternative is achieved by SiO_2 **105** deposition filling trenches between the planar Si **104** structures created by the etching of the Si substrate **104**. In one particular embodiment, FIG. **2**A shows a top view of an exemplary design of a platform support arm **102***a* comprised of alternating Si **104** and SiO_2 **105** stripes formed by this process. In an alternative embodiment of a support arm **102***b*, a Si **104** meandering structure **205** is filled with SiO_2 **105** as shown in FIG. **2**B. The SiO_2 deposition process used in the creation of the support arms **102** can be selected from any silicon oxide deposition methods including, but not limited to, low-pressure chemical vapor deposition (LPCVD), plasma-enhanced chemical vapor deposition (PECVD), and thermal oxide deposition. It should be understood that during operation there will be a temperature gradient across the length of each of the arms **102** as they act to thermally isolate the platform **110** from the ambient environment. The length and shape of each of the support arms **102** can vary between the embodiments of the present invention and are determined by the desired thermal isolation levels and sensor performance, as well as by the fabrication process requirements.

FIGS. **3**A-**3**E show an exemplary fabrication process flow (referred to as "design **A1**" herein) for the Si/SiO_2 hybrid ovenized platform **320** using a silicon-on-insulator (SOI) wafer process and a deep reactive ion etching (DRIE) of the Si **104** to release the platform **320**, in accordance with an embodiment of the present invention. The Si/SiO_2 hybrid support arm **102** structure is realized by refilling SiO_2 **105**, in step (b) **322** shown in FIG. **3**B into trenches **302** created within the upper layer of Si **104** in step (a) **321** shown in FIG. **3**A. A thin-film electrical interconnect layer such as metal or poly-Si traces **306** may be added on top of the refilled SiO_2 **105** layer **304** in step (c) **323** shown in FIG. **3**C. The support arms **102** may optionally then be patterned and defined **308** by deep reactive ion etching (DRIE) in step (d) **324** shown in FIG. **3**D. Step (d) **324** can be skipped if the Si/SiO_2 hybrid structure **102** is designed in a ring-like or perimetral structure surrounding the Si **104** platform. As can be seen in FIG. **3**E, the platform is finally released **310** in step (e) **325** by performing DRIE on the reverse side of the platform. It should be understood that in this embodiment as well as elsewhere in the Figures and other embodiments, the dotted line is meant to indicate areas located behind of or in front of the plane visible in the cross-sectional view. Accordingly, these ovenized platform fabrication process steps are fully compatible with and can be incorporated within standard IC fabrication processes. One skilled in the art should understand that the order of the intermediate steps may be interchangeable in this process as well as the processes disclosed below.

Turning now to FIGS. **4**A-**4**E, an exemplary fabrication process flow is shown in accordance with an embodiment of the present invention (referred to as "design A2" herein) **420** which is a variation of design A1 **320** described above but additionally incorporates a standard CMOS integration process. Accordingly, steps (a) **421** and (b) **422**, illustrated here in FIGS. **4**A and **4**B, are identical to those seen in FIGS. **3**A and **3**B respectively. The standard CMOS circuitry incorporation process is completed in step (c) **423**, shown in FIG. **4**C which occurs after the oxide **105** refill in step (b) **422**, shown in FIG. **4**B. In this embodiment of the process flow, instead of using DRIE to release the platform in the final step (e) **425**, seen in FIG. **4**E, alternatively, a buffered hydroflu-

oric (BHF) or hydrofluoric (HF) vapor release **410** can be used to achieve a similar platform structure as that shown in FIG. **3** for design A**1** **320**. In this embodiment, CMOS circuitry **306** can be integrated on or off the platform.

FIGS. **5**A-**5**G illustrate yet another variation of a fabrication process flow (referred to as "design B**1**" herein) to fabricate the platform **520** using silicon oxide release in accordance with an embodiment of the present invention. While step (a) **521**, shown in FIG. **5**A, is identical to those described in the previous two exemplary process flows, the remaining steps differ in this embodiment. After the initial DRIE process in step (a) **521**, step (b) **522** comprises first depositing a layer of silicon nitride **107** and then depositing a layer of silicon oxide **105** thereon, thereby effectively filling the DRIE-created trenches **302** as well as layering the planar surface of the platform **520** as depicted in FIG. **5**B. A second silicon nitride **107** layer is deposited in step (d) **524** to cover the oxide **105** layer and sandwich it between two layers of nitride **107**. In this exemplary fabrication process, areas **504** for release, located behind and in front of the visible plane in the dotted region, are formed by removal of the nitride **107** layer in step (f) **526**, shown in FIG. **5**F, when the support arms **102** are patterned **308**. In step (c) **523**, depicted in FIG. **5**C, the support arm pattern may be etched (if not already patterned) and the subsequently exposed buried oxide **105** in those etched areas is removed by reactive ion etching (RIE). In this step, while not visible in this cross sectional view, the removal of the Si **104** and thereafter of the buried silicon oxide **105** occurs primarily in the area occupied by the gaps between the support arms **102** depicted in FIGS. **1**A-**1**B. It should be obvious and understood by one skilled in the art that FIGS. **5**A-**5**G only show one variation of such a manufacturing process flow design and that the support arm **102** patterning **308** step can either be completed in step (a), as shown in FIG. **5**A, or right before the oxide release **510** occurs in step (g) **527** seen in FIG. **5**G. Similarly, as was the case with designs A**1** **320** and A**2** **420**, design B**1** **520** is also fully compatible with and integrable within standard IC fabrication processes.

FIGS. **6**A-**6**H show yet another variation of a fabrication process flow (referred to as "design B**2**" herein) **620** which is similar to design B**1** **520** but also incorporates a standard CMOS **416** integration process. In this flow, a variation of the manufacturing process is shown wherein DRIE trenches **302** are created in step (a) **621** and additional release holes **615** are created on the ovenized platform in step (g). In this process, the silicon nitride **107** oxide **105** nitride **107** alternating layers are deposited separately in steps (b) **622**, (c) **623**, and (d) **624** respectively, as seen in FIGS. **6**B-**6**D, to then form lateral etch stops **604** made in the top layer of nitride **107** in step (d) **624** shown in FIG. **6**D. To achieve the structure of the nitride **107** lateral etch stops **604**, first, the middle oxide **105** layer is patterned by etching to provide the depressions **602** within which the etch stops **604** will be formed upon the deposition of the second nitride **107** layer. These lateral etch stops **604** provide a complete seal of the refill oxide **105** and ensure the Si/SiO_2 structure is not attacked in the final oxide release step (h) **628**. Then, CMOS circuitry **416** is added in step (e) **625**, shown in FIG. **6**E, and thin-film electrical interconnects such as metal or poly-Si traces **306** are added on the top surface of the platform **620** in step (f) **626**, shown in FIG. **6**F. Support arms are patterned **308** in step (g) **627** after the standard CMOS circuitry **416** integration process is completed as shown in FIG. **6**G. The optional additional release holes **615** may also be etched in step (g) **627**. These release holes **615** serve to further reduce the total release time of the oxide-release **610** occurring in step (h) **628**, shown in FIG. **5**H, and thus speed up the fabrication process.

FIGS. **7**A-**7**B illustrate a more detailed view of the Si/SiO_2 hybrid structure achieved in step (d) **624** of design B**2** **620**. As shown in FIG. **7**A, which is a cross-section along the heat conduction path, and in FIG. **7**B, which is a cross-section perpendicular to the conduction path, the refilled oxide **105** layer is protected by the top and bottom layers of nitride **107** and therefore will not be attacked in the oxide release step. In this manner, the geometry of this configuration coupled with the two layers of silicon nitride **107** protects Si/SiO_2 hybrid structure from the subsequent oxide release steps. While the silicon nitride **107** may have a higher thermal conductivity than silicon oxide **105**, the nitride **107** layer is preferably made very thin (≤1000 Å) so as to ensure that the heat conduction of the thin film nitride is negligible.

FIGS. **8**A-**8**G demonstrate yet another variation of a fabrication process flow (referred to as "design C**1**" herein) **820** that uses a Si DRIE process to create the release holes **815** from the handling layer side of the SOI wafer in accordance with an embodiment of the present invention. Steps (a) **821**-(b) **822** in this process, shown in FIGS. **8**A-**8**B, are analogous to the steps shown in FIGS. **6**A-**6**B, wherein DRIE trenches **302** are made followed by an alternating layering of nitride **107**|oxide **105**|nitride **107** on the top surface of the platform **820**. Thereafter, in step (c) **823** depicted in FIG. **8**C, thin-film electrical interconnects such as metal or poly-Si traces **306** are added on the top surface, which is the device layer side of the platform. In this process, unlike those described previously, oxide **105** deposited on the bottom surface, which is the handling layer side (reverse side) of the platform **820**, is patterned to create release holes **815** in step (d), as illustrated in FIG. **8**D. It should be noted that, optionally, the support arms may be patterned **308** and the Si **104** may be removed in step (e) **825**, as shown in FIG. **8**E. A subsequent oxide release **810** step (g) **827**, shown in FIG. **8**G, is completed from the reverse side of the wafer. Given that the oxide release **810** occurs from the handling layer side (reverse side) where the holes **815** have been made, the device layer side (top side) can be protected with photoresist during the release steps. This allows for a simple silicon nitride **107**|oxide **105**|nitride **107** refill process to be applied in step (b) **822** to the top side of the platform.

FIGS. **9**A-**9**H show yet another variation of a fabrication process flow (referred to as "design C**2**" herein) **920** based on design C**1** **820** which also incorporates a standard CMOS **416** integration process. The steps involved in this exemplary process flow are identical to those of design C**1** **820** described above and shown in FIGS. **8**A-**8**G with the exception of one additional intervening step wherein CMOS circuitry **416** is added to the platform. In this process, as can be seen in step (c) **923**, shown in FIG. **9**C, CMOS circuitry **416** is integrated onto the platform after the silicon nitride-oxide-nitride layer deposition step (b) **922**, shown in FIG. **9**B. The remaining steps (d) **924**, (e) **925**, (f) **926**, (g) **927**, and (h) **928**, shown in FIGS. **9**D-**9**H, are analogous to the steps respectively depicted in FIGS. **8**C-**8**G.

In a preferred embodiment of the ovenized platform, a temperature sensor **1002***a* and a heater **1004***a* can be incorporated into the Si **104** layer of the SOI wafer and shielded with the SiO_2 **105** refill process as can be seen in FIGS. **10**A and **10**B. In FIG. **10**A both the temperature sensor **1002***a* and the bulk Si heater **1004***a* are displaced in an upper Si **104** layer of the platform **1020**, while in FIG. **10**B both are

displaced in a lower Si layer of the platform **1020**. In other preferred embodiments, different metals can be deposited during a metal deposition step in order to form the temperature sensor **1002***b* and heater **1004***b* as shown in FIG. **10**C. For example, a thin Pt film is the preferred material commonly used to comprise the temperature sensor and heater although a variety of thin film metals can be used. Alternatively, thin film resistors comprised of two suitable materials such as Pt, Ni, Cr, or one of their alloys, with such resistors having different base resistances at a given temperature and different temperature coefficients of resistance (TCR), can be deposited to form a temperature sensor **1002***b* and provide a fixed-temperature voltage intersect when provided a constant current input on both branches of the circuit. A surface mounted temperature sensor **1002***c* resistor and/or heater **1004***c* can also be soldered onto the platform with a metal pad integrated onto the platform as shown in FIGS. **10**D and **10**E respectively. It should be obvious to and understood by one skilled in the art that all the different configurations of heater and temperature sensors are independent from the process flow designs (including but not limited to designs A**1 320**, A**2 420**, B**1 520**, B**2 620**, C**1 820** and C**2 920**) and can be included in any variation thereof.

FIGS. **11**A-**11**E show a variety of configurations of heater **1004***a-c* and temperature sensors **1002***a-c* on an ovenized platform **1120** integrated with CMOS circuitry **416**. The embodiments of the platform **1120** shown in FIGS. **11**A-**11**E are analogous to those shown in FIGS. **10**A-**10**E, except that each also depicts the placement and configuration of CMOS circuitry **416** integrated on the platform **1120**.

The fabrication process of the ovenized platform is compatible with standard MEMS fabrication processes as well. FIGS. **12**A-**12**J show an exemplary SOI fabrication process of an ovenized platform **1220** integrated with inertial sensors **1202** in accordance with a preferred embodiment of the present invention. In this embodiment, the inertial sensor structures **1202** are defined together with the Si trenches **302** of the support arms **102** simultaneously in step (a) **1221**, shown in FIG. **12**A, and then refilled with SiO_2 **105** in step (b) **1222** as shown in FIG. **12**B. Electrical interconnects **306** are added on the top surface of the platform **1220** in step (c) **1223**, shown in FIG. **12**C, after which silicon oxide patterning **1204** is added on the reverse side of the platform in step (d) **1224**, shown in FIG. **12**D, and optional DRIE patterning **308** may be optionally performed for the support arms **102** in step (e) **1225**, shown in FIG. **12**E. The inertial sensors **1208** are then released while the Si/SiO_2 support arms **102** are protected with photoresist **1206** as shown in step (f) **1226** seen in FIG. **12**F. FIGS. **12**G-**12**J illustrate how, with subsequent cap wafer bonding occurring as illustrated in steps (g) **1227**, (h) **1228**, and (j) **1230** (with different bonding cavity pressure and the creation of vacuum spaces **1232**) as well as the support arms being released **1210** through DRIE in step (i) **1229**, a fully integrated inertial sensor **1208** with an ovenized platform **1220** is fabricated on the wafer level. While this process flow only shows the integrated process with inertial sensors **1210** based the fabrication process flow of design A**1 320** seen in the FIG. **3** series, this integrated process can similarly be applied to design B**1 520** and C**1 820** and should be obvious to and understood by one skilled in the art to be applicable to other process schemes as well. The top cap **1214** and bottom cap **1216** as well as the sensor cap **1212** can be made of any compatible materials although Si and glass are the most common materials suitable for wafer-level packaging. Vertical vias **1218** may be applicable in this integrated process and can be included in the top cap **1214** fabrication. When vertical vias **1218** are not used, however, wirebond pads can be formed in step (c) **1224**, shown in FIG. **12**C, and exposed after bonding the top cap **1214** in step (h) **1229** as seen in FIG. **12**H.

Similarly, the standard CMOS process can be integrated into this process as well and such an exemplary fabrication process flow is shown in FIGS. **13**A-**13**K in accordance with a preferred embodiment of the present invention. Steps (a) **1321**, (b) **1322**, (d) **1324**, (e) **1325**, (f) **1326**, (g) **1327**, (h) **1328**, (i) **1329**, (j) **1330**, and (k) **1331** of this platform **1320** fabrication process is analogous to steps (a) **1221**-(h) **1229** of the platform **1220** fabrication process with the exception of step (c) **1323** in this process wherein CMOS circuitry **416** is integrated into the platform **1320**. While this process flow only shows the integrated process with inertial sensors based on the fabrication process flow of design A**2 420**, it should be obvious to and understood by one skilled in the art that this integrated process can likewise be applied to design B**2 620** and C**2 920** as well as other process schemes.

The ovenized platform and its fabrication processes are versatile and can be easily implemented with different packaging schemes. FIGS. **14**A-**14**E illustrate several variations of packaging schemes **1420***a-e*, each with different sensors **1408**, including both packaged sensors **1404** and unpackaged sensors, in accordance with alternative embodiments of the present invention respectively. While the drawings only demonstrate the inventive concept as applied to design A**1 320**, it should be obvious to and understood by one skilled in the art that the same concept can be applied to designs B**1 520** and C**1 820** as well as other ovenized platform process flow designs. FIG. **14**A shows a packaged sensor (or a 3rd party inertial sensor/IMU) **1404** which can be bonded **1412** on the platform using flip-chip solder bonding or metal (or semiconductor) eutectic bonding in the first exemplary packaging scheme **1420***a*. The sensor **1404** and the platform are then packaged into an electronic chip package (which may be a standard ceramic package in this and other embodiments) **1414** through a vacuum seal process to create a vacuum cavity **1406** and provide thermal isolation. FIG. **14**B shows the second exemplary packaging option **1420***b* a similar concept being utilized to integrate an application-specific integrated circuit chip (ASIC) **1416** and a Si sensor (which itself may be either a packaged or an unpackaged Si die) **1408** onto the platform which is then vacuum sealed in an electronic chip package **1414**. Accordingly, when an unpackaged sensor die **1408** is used, this method only applies to those sensors which require vacuum packaging. FIG. **14**C shows a similar scheme **1420***c* that attaches the ASIC **1416** and sensor **1408** onto the platform and connects them with wirebonding **1402** instead of metal solder or eutectic bonding. Similarly, when an unpackaged sensor die **1408** is used, this method only applies to those sensors requiring vacuum packaging. FIG. **14**D shows a configuration **1420***d* where the sensor **1408** and ASIC **1416** are stacked on top of each other in which the positioning of the sensor **1408** relative to the ASIC **1416** can vary or be interchangeable (i.e. either the sensor **1408** on top of the ASIC **1416** or the ASIC **1416** on top of the sensor **1408**) and may depend on the size of the respective dies. The stack may be connected by a bond **1412** on the platform using either flip-chip solder bonding or other metal or semiconductor eutectic bonding. FIG. **14**E shows an alternative configuration to that of FIG. **14**D where a wirebonding **1402** connection scheme that integrates the sensor **1408** and ASIC **1416** stack onto the ovenized platform is utilized instead of flip-chip solder bonding or other metal or semiconductor eutectic bonding.

FIGS. **15**A-**15**F show the package schemes **1520***a-f* using an ovenized platform integrated with CMOS circuitry **416** respectively in accordance with alternative embodiments of the present invention. While the drawings only demonstrate the inventive concept as applied to design A**2** **420**, it should be obvious to and understood by one skilled in the art that the same concept can be applied to designs B**2** **620** and C**2** **920** as well as other ovenized platform fabrication process flow designs. FIG. **15**A illustrates packaging scheme **1520***a* in accordance with an embodiment of the present invention wherein a packaged sensor (which may be a 3rd party inertial sensor/IMU) **1404** is bonded **1412** on the platform using flip-chip solder bonding or metal (or semiconductor) eutectic bonding after which the sensor **1404** and the platform are packaged into an electronic chip package (which may be a standard ceramic package) **1414** with a vacuum seal process to create a vacuum cavity **1406** and provide thermal isolation. FIG. **15**B shows another scheme **1520***b* using a similar concept to integrate an ASIC **1416** and a Si sensor (which itself may be either a packaged or an unpackaged Si die) **1408** onto the platform which is then vacuum sealed in an electronic chip package. Accordingly, when an unpackaged sensor die is used, this method only applies to those sensors **1408** which require vacuum packaging. FIG. **15**C shows a similar scheme **1520***c* that also attaches the ASIC **1416** and sensor **1408** onto the platform, but instead electrically connects them with wirebonding **1402**. Similarly, as in the previous instances, when an unpackaged sensor die is used, this method only applies to those sensors **1408** requiring vacuum packaging. FIG. **15**D shows yet another configuration **1520***d* stacking the sensor **1408** and ASIC **1416** on top of each other wherein the order or the positioning of the sensor **1408** relative to the ASIC **1416** can vary or be interchangeable (i.e. either the sensor **1408** on top of the ASIC **1416** or the ASIC **1416** on top of the sensor **1408**) and may depend on the size of the respective dies. The stack may be attached by a bond **1412** on the platform using flip-chip solder bonding or metal (or semiconductor) eutectic bonding as illustrated in FIG. **15**D or may alternatively use a wirebonding **1402** connection scheme that integrates the sensor **1408** and ASIC **1416** stack onto the ovenized platform as shown in FIG. **15**E. FIG. **15**F shows another alternative configuration **1520***f* scheme where the integrated sensor die (which may or may not contain integrated circuits in the die) **1409** is attached to the ovenized platform with all or part of the readout circuits integrated onto the platform.

The ovenized platform can also embody configurations of wafer-level packaging for individual sensor dies. FIGS. **16**A and **16**B each show the cross section of a variation of such a packaging scheme in accordance with preferred embodiments of the present invention. In this embodiment, the sensor (or device) **1408** can either be a fully packaged sensor (or device) or an unpackaged sensor (or device) otherwise designed to be compatible for this integration. The preferred embodiment of the ovenized platform depicted in FIG. **16**A comprises a sensor **1408**, a top cap **1602**, and a bottom cap **1604**. The sensor **1408**, which may be a packaged sensor displaced entirely within a vacuum cavity **1406** defined by the top cap **1602** and the upper surface of the device layer side of the platform, may be attached by connection means **1412** using metal solder or eutetic bonding to the leads **1608** on the upper surface of the platform located on the device layer side (top side) thereof. Both the top cap **1602** and the bottom cap **1604** may be made of either Si, glass, or other materials suitable for encasing the platform-and-sensor combined structure. This integration may be accomplished on the wafer level with the assistance of a pick-and-place machine or through the utilization of other sorting approaches. Once the sensor (or device) **1408** is integrated onto the platform, the entire wafer is then bonded with a top cap **1602** and bottom cap **1604** after the support arm release. FIG. **16**A shows the packaging scheme **1620***a* using platform design A**1** **320** and FIG. **16**B shows the packaging scheme **1620***b* using platform design A**2** **420** incorporating CMOS circuitry **416**. While the drawings only demonstrate the concept using design A**1** **320** and A**2** **420**, it should be obvious to and understood by one skilled in the art that the same concept can be applied to design B**1** **520**, B**2** **620**, C**1** **820**, C**2** **920** as well as other ovenized platform fabrication process flow designs.

It should be noted that the features illustrated in the drawings are not necessarily drawn to scale, and features of one embodiment may be employed with other embodiments as the skilled artisan would recognize, even if not explicitly stated herein. Descriptions of well-known components may be omitted so as to not unnecessarily obscure the embodiments.

While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from this detailed description. The invention is capable of myriad modifications in various obvious aspects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature and not restrictive.

The invention claimed is:

1. An ovenized silicon platform comprising:
at least one silicon layer;
at least one silicon oxide layer;
a hybrid Si/SiO_2 platform support structure,
wherein said support structure is formed by depositing silicon oxide within trenches formed by a deep reactive ion etching of a silicon layer to create alternating layers of silicon and silicon oxide configured to thermally isolate the platform from temperature fluctuations; and
at least one thin-film electrical interconnect displaced on the top surface of said platform.

2. The platform of claim **1** further comprising: at least one element selected from the group comprising CMOS circuitry, thermal sensor, heater, and inertial sensor.

3. The platform of claim **1** wherein the alternating layers of silicon and silicon oxide within the platform support structure are separated by a layer of silicon nitride.

4. The platform of claim **1** wherein the at least one silicon layer is a device layer of a silicon-on-isolator wafer.

5. The platform of claim **2** comprising at least one thermal sensor and at least one heater wherein said at least one thermal sensor and said at least one heater are each positioned within a layer of silicon.

6. The platform of claim **2** comprising at least one thermal sensor and at least one heater wherein said at least one thermal sensor and said at least one heater are each positioned on the top surface of said platform.

7. The platform of claim **1** wherein the thin-film electrical interconnect is a trace comprising metal or polysilicon.

8. A method for fabricating an ovenized silicon platform, said method comprising the steps of:
deep-reactive-ion-etching trenches into a layer of silicon on one side of said platform;
forming a recess on a side of the platform opposite to that of said trenches;
depositing a layer of oxide onto a top layer of the platform to refill said trenches

thereby having a patterned platform support structure of alternating layers of silicon and silicon oxide that provides thermal isolation for the platform;

attaching conductive traces onto a surface of the platform; and

releasing said support structure.

9. The method of claim **8** further comprising the step of:

integrating CMOS circuitry with the platform.

10. The method of claim **8** further comprising the steps of:

depositing a first layer of nitride onto a layer of silicon prior to depositing a layer of oxide on a top layer of the platform; and

then depositing a second layer of nitride onto the layer of oxide to create a layer of oxide sandwiched between layers of nitride deposited on a top surface of the platform.

11. The method of claim **10** further comprising the steps of:

patterning the silicon oxide layer to create depressions therein; and

encapsulating said depressions with nitride during the deposition of the second layer of nitride to create lateral etch stops.

12. The method of claim **8** further comprising the steps of:

defining at least one inertial sensor along with said trenches during the deep-reactive-ion-etching step;

releasing said at least one inertial sensor;

fitting a sensor cap over said at least one inertial sensor;

fitting a top cap on a top surface of said platform; and

fitting a bottom cap on a bottom surface of said platform.

13. The method of claim **12** further comprising the step of:

integrating CMOS circuitry with the platform.

14. The method of claim **8** further comprising the steps of:

attaching at least one of an unpackaged sensor or a packaged sensor to a top surface of the platform;

attaching said platform within an electronic chip package; and

covering said package with a lid.

15. The method of claim **14** further comprising the steps of:

vacuum sealing said ceramic package.

16. The method of claim **14** where in the sensor attachment step is accomplished by either flip-chip bonding, eutectic bonding, or wirebond connection.

17. The method of claim **14** wherein the electronic chip package is ceramic.

18. The method of claim **14** further comprising the step of:

integrating CMOS circuitry with the platform.

19. The method of claim **15** further comprising the step of:

integrating CMOS circuitry with the platform.

20. The method of claim **16** further comprising the step of:

integrating CMOS circuitry with the platform.

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